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Report RM-146



Guidelines for Measuring the Physical, Chemical, and Biological Condition of Wilderness Ecosystems

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Guidelines include a large number of specific measures to characterize the existing condition of wilderness resources. Measures involve the atmospheric environment, water chemistry and biology, geology and soils, and flora. Where possible, measures are coordinated with existing long-term monitoring programs. Application of the measures will allow more effective evaluation of proposed new air pollution sources.

Keywords: Monitoring, Wilderness, Baseline Conditions, Air Pollution, Atmospheric Deposition

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Guidelines for Measuring the Physical, Chemical, and Biological Condition of Wilderness Ecosystems

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Foreword

This report is the product of an effort to poll the scientific community about the most appropriate techniques to be used to measure the condition of wilderness ecosystems. These techniques recognize the constraints imposed by the statutory designation of wilderness. They are focused on monitoring needed to support the air resource management responsibilities of the Forest Service and other managers of Class I areas, as mandated by the Clean Air Act.

This report was prepared as part of a contract effort between the Rocky Mountain Forest and Range Experiment Station, and Science and Policy Associates, Inc. of Washington, D.C. SPA crafted a process that included a large group of scientific talent (listed at the end of the Guidelines) organized to develop a consensus product with an ever-widening group of interested parties. These Guidelines specifically result from a formal public review of earlier drafts. Review comments and the responses to them are available from the Rocky Mountain Station.

Readers should keep in mind that wilderness monitoring is complex and controversial. Improvements are likely to result only through experience with the application of these guidelines in diverse locations over the breadth of ecosystems that populate the Wilderness system in the US. Toward that end the Rocky Mountain Station is continuing to develop and record experiences with the application of these Guidelines. Three specific examples are worth mentioning:

1. The Wyoming State Office of the USDI Bureau of Land Management is applying the Guidelines to selected wilderness study areas in the western part of the State and evaluating their utility. This work was initiated in 1987 and will be ongoing for 5 years.

2. The Idaho National Engineering Laboratory, a national laboratory under the Department of Energy, is conducting a 2 year technical review and critique of the Guideline methods. INEL work is focused on the Bridger Wilderness.

3. The Atmospheric Deposition Effects research unit at the Rocky Mountain Station is conducting continued long term study of wilderness ecosystems using both direct stress/response and general biogeochemical procedures. A focus of this research is to

provide Federal land managers and regulators with tools to discharge appropriate and effective management of air resources as one of the multiple natural resources of wilderness.

Thus, we recognize that the guidance provided in this report will need periodic review. It is likely that versions of these Guidelines will be updated every 5 years.

The Need for Guidelines

Guidelines for determining current conditions of sensitive resources in Wilderness ecosystems have several purposes. FLMs and regulators need implementable measures to determine if significant changes are occurring in Wilderness areas in order to comply with the law and effectively steward these resources. Air quality decisions must be made now; they cannot await full scientific understanding or development of ideal measurement and monitoring techniques. Information concerning current conditions also will be valuable in fulfilling FLMs' broader stewardship functions for these special areas.

Guidelines are essential to the FLMs' air quality and management missions as well as to the process of sound scientific research. Standardized methods are crucial so that comparable data are produced from different studies and sites. Guidelines help ensure reproducible results and document the procedures used so that future efforts can be related to old data. Uniformity of technique also is critical for appropriately extrapolating results. Scientifically credible protocols provide the needed basis for making sound regulatory, legal, and management decisions.

One final note: These protocols were originally developed to apply to alpine and subalpine ecosystems in areas where the air quality is considered to be clean. Following their development it became clear that many of the measures recommended were more generally applicable. Nevertheless, caveats restricting the protocols to alpine and subalpine conditions are widespread in the document. The reader is cautioned to use the protocols accordingly.

Douglas G. Fox

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INTRODUCTION

Background

This report presents appropriate scientific protocols to measure current conditions of air quality related values (AQRVs) in Wilderness areas. These protocols are intended to be guidelines for quantifying the existing status of AQRVs, monitoring for changes from these existing conditions, and subsequently, evaluating whether the changes are naturally occurring or the result of man-caused air pollution/chemical deposition. Certain regulatory and management requirements have constrained the development of the protocols presented in this report. These constraints are explained fully in the first section.

The scientists and contributors that developed this document (listed at the end of these Guidelines) were divided into six work groups, with the Work Group Leaders responsible for the development of protocols for the five technical areas: 1) Atmospheric Environment, 2) Soils and Geology, 3) Aquatic Chemistry and Biology, 4) Vegetation, and 5) Regulatory and Management Constraints. A sixth group, Government Applications, was added shortly after the project began.

A meeting was held in Fort Collins, CO in January 1986 to bring scientists developing the protocols together with some of the federal land managers (FLMs) and regulators who will be the users of the guidelines. Discussions of draft lists of measures resulted in substantial progress toward consensus. After further internal review of the lists, the Work Groups began to prepare their draft protocols.

A second meeting was held in June 1986 to 1) provide an opportunity for the project team to refine the draft protocols; 2) widen the sphere of participation in reviewing and refining protocols by involving additional key external users and scientists; and 3) aid in a smooth transition to the larger consensus development meeting, the Public Review. Consensus building among diverse stakeholders and other interested parties is an important component of this project. Involving key industry, state, federal, and environmental groups prior to the public review meeting enabled the Work Group Leaders to address emerging technical concerns early in the process.

The final task of this phase of the project was the Public Review of the draft document. As part of this process, a Public Review Meeting, announced in the Federal Register, was held in Boulder, CO in December 1986. The purpose of this meeting was twofold: 1) to educate the participants on FLMs' needs and regulatory and management constraints, and 2) to allow review

and discussion on key technical issues, and to develop consensus on these issues. The comments received during this meeting, and written comments from the comment period following the meeting, were addressed by the Work Group Leaders during the final revision of this document.

Protocol Development

Several basic project assumptions were discussed and clarified at the June meeting to provide guidance in the preparation of these protocols:

1. The protocols are being developed initially for application to high-elevation western areas.
2. The measurements and protocols will be used by FLMs and air quality permitting authorities specifically for the protection of "air quality related values" of national Wilderness areas designated as class I areas under the Clean Air Act.
3. The measurements are not intended to be a research project, but will be conducted to fill specific resource management regulatory information needs.
4. In most cases, the land manager's/permitting authority's needs will be met by the measurement of change in the most sensitive component of the ecosystem. The determination of whether a change is adverse is the responsibility of the FLM.

Not all possible attributes can be measured, and the list must be parsimonious and practical. An attribute should have ecological significance, and should be likely to change as a consequence of air quality effects. Ideally, it should change only in response to changes in air quality and nothing else; clearly an impossibility! The attribute measured and the method of measurement must be defensible to a consensus of the scientific community. Non-destructive methods are preferable, not only because of Wilderness regulations but also because repeated measurements of the same organism or assemblage is advantageous. Attribute variables that can be monitored with low frequency should be given consideration over those that require many measurements at intervals of less than one year. Only those attributes that can be readily measured with high accuracy should be considered.

Problem

There are several important reasons for systematically establishing guidelines for methods and techniques for monitoring current AQRV conditions and tracking future condition changes. These reasons include the following:

1. To provide clarity internally for the

Forest Service in Wilderness management, planning, operations, and decisions, and externally to States and prospective new air pollution sources about what the FLM considers necessary in monitoring the current conditions of certain AQRVs and potential air pollution-caused changes in those AQRVs;

2. To reduce the period of time needed to complete AQRV impact analyses during the air quality permit review process;

3. To provide a standardized approach to AQRV impact analysis so that analyses by different parties can be compared, and so that analyses in different permitting cases can be compared with one another;

4. To provide a framework for due process with respect to both the Forest Service's AQRV impact analyses and findings and its broader Wilderness protection mandate, thus enhancing the defensibility of such analyses and findings in regulatory and judicial proceedings; and

5. To the extent feasible, to minimize conflicts over technical issues surrounding AQRV sampling, monitoring, and measurement, thus limiting disagreement where possible to value judgments about whether a projected AQRV effect is considered an "adverse impact."

General Issues

Guidelines of several types are needed. First, however, it must be established what should be measured to gauge man's impacts on ecosystems. Techniques and sampling and analytic procedures then must be determined that are appropriate to the physical, regulatory, and management constraints of Wilderness areas. These constraints include rugged, remote, often high-altitude settings subject to extreme physical conditions; Wilderness Act statutory and related regulatory prohibitions; Clean Air Act requirements for permitting; and management constraints such as budget limitations.

Major problems only touched on in these guidelines, but still requiring further consideration, are:

1. Sampling intensity and location are key variables that must be determined, given the degree of natural variability and physical limits on practical measurements. Not only in-depth knowledge of the natural systems, but also statistical design considerations bear on this issue. Technical approaches must be developed for the most practical and representative ways to make the required measurements in Wilderness areas. Guidelines are needed for both on-site and laboratory analysis so that sources of error can be minimized. A major challenge is designing sampling schemes that can adequately represent the diverse physical, chemical, and biological variables.

1. Guidelines also are needed for data reduction, analysis, and archiving. These post-measurement treatments of data and samples are an important consideration for developing results that will still be useful in the distant future. A quality assurance plan should be developed along with the other protocols to ensure reliable and meaningful results. Quality assurance/quality control (QA/QC) is essential to

characterize adequately the sources of error and the inherent uncertainties in the data collected.

2. Major concerns are how to address the inevitable tradeoffs between what measurements ideally are desirable scientifically and what is actually possible under the physical and legal constraints imposed by high-elevation Wilderness sites and limited resources. It could be argued that not enough is known even to determine what to measure, when, or how. This approach is not a luxury that FLMs can indulge. The task at hand is the art of the possible; the immediate goal is to determine the best possible approach, fully document it, and then proceed to use it knowing it is not ideal.

The guideline protocols presented within this document are not intended to represent all that can be measured within Wilderness ecosystems. Conversely, not all of the measurements suggested here may be necessary for a given site or situation. These protocols are presented as a reasonable list of measurements for establishing current conditions in alpine and subalpine areas to aid in detecting changes in the future. In addition, a mechanism must be provided for the integration of data collected on aquatic chemistry and biota, catchment soils, vegetation, and atmosphere. This integration will be critical to maximize confirming evidence for measured effects.

The high degree of scientific uncertainty about how atmospheric chemicals influence natural ecosystems means no single widely accepted view exists on many issues. Consensus building must be part of the entire process so that the greatest degree of scientific credibility possible can be achieved. Part of the purpose of this project is to educate the research and technical community on what the FLM needs are, the reasons the FLM cannot wait for ideal approaches to be developed, and the legal and management constraints under which the FLM must act. The best current scientific judgment must be made, discussed, and agreed on to accomplish our goals.

Organization of Document

The first section of this document presents the paper prepared by Work Group 5, Regulatory and Management Constraints. The following sections present each set of protocols developed by Work Groups 1 through 4. The members of the Work Groups, including those in Work Group 6, Regulatory Applications, are listed on page 48, at the end of these Guidelines.

REGULATORY AND MANAGEMENT CONSTRAINTS

This chapter briefly explains constraints on development and application of scientific guidelines for the measurement and analysis of "air quality related values" (AQRVs) in wilderness areas. These constraints are imposed by the Clean Air Act (CAA) and the Wilderness Act (WA), the physical location of remote areas, weather, altitude, and other such factors. The measures included in this document have been

shaped and limited in their approach by the constraints identified here. Therefore, this chapter is intended to assist readers in developing a full understanding and appreciation of the possible constraints on the development and implementation of the guidelines.

Clean Air Act Context

The Clean Air Act Amendments of 1977 included a program for prevention of significant deterioration of air quality, generally referred to as the "PSD" program. In part, this PSD program was intended to safeguard the air quality related values (AQRVs) of Wilderness areas and National Parks which the statute designates as "Class I areas." This "Class I" designation allows only very small "increments" of new pollution above already existing air pollution levels within the area, and subjects each such area's AQRVs to special protection considerations under the Clean Air Act.

Under the CAA, the appropriate Federal Land Manager (FLM) is charged with an "affirmative responsibility" to protect the AQRVs of Class I areas from adverse air pollution impacts. In the case of the Forest Service, the FLM's affirmative responsibility to protect AQRVs has been delegated to the Regional Forester level.

The FLM's "affirmative responsibility" is implemented, in part, through the PSD new source review process, a preconstruction review and permitting program for major new or expanding sources of pollution. Any major facility seeking a new source permit for location or expansion in a Clean Air area must meet several requirements, among them the Class I and/or II increments, the so-called AQRV "adverse impact test," and the Best Available Control Technology (BACT) evaluation. In the PSD permitting process, the FLM determines whether a proposed source's emissions will have an adverse impact on Class I AQRVs.

New source permit applicants submit plans to the permitting authority, who examines the proposed location of the facility, its general design, projected air pollution emissions, and potential impacts. When a proposed source's emissions may have an impact on a Class I area, the permitting authority (EPA, or the State, if EPA has delegated PSD authority to that State) alerts the Federal Land Manager. The FLM then conducts an "adverse impact determination" to assess the impact the projected pollution level increases would have on the Class I area. The application review process may take as little as 30 days or, with complex or controversial projects, possibly longer than 1 year. The FLM's adverse impact determination must be completed within this period.

Wilderness Act Context

Legal Direction for Managing Wilderness

Congress established the National Wilderness Preservation System in 1964 "to secure for the American people an enduring resource of wilderness." The Wilderness Act describes the basic purpose of wilderness, defines the

wilderness resource and character, and establishes management direction to preserve an enduring wilderness resource. This direction is the foundation for the implementing regulations, found in 36 CFR 293, 36 CFR 291, and Forest Service policy in FSM 2320.

The preservation of wilderness character means striving to preserve "untrammelled" natural conditions and "outstanding opportunities for solitude." This meaning applies to all wilderness management activities, including resource monitoring of all kinds. Minimizing the effects of human use or influences on natural ecological processes is the most important principle of wilderness management. To clarify management direction, the Act spells out specific prohibitions, while allowing only minimum necessary exceptions:

Except as specifically provided for in this Act, and subject to existing private rights, there shall be no commercial enterprise and no permanent road within any wilderness area designated by this Act and, except as necessary to meet minimum requirements for the administration of the area for the purpose of this Act (including measures required in emergencies involving the health and safety of persons within the area), there shall be no temporary road, no use of motor vehicles, motorized equipment or motorboats, no landing of aircraft, no other form of mechanical transport, and no structure or installation within any such area. [Section 4(c)]

Forest Service wilderness managers must be the leaders in demonstrating that wilderness management tasks (including monitoring of air pollution impacts on resources) can be done without structures, installations, or the use of motorized equipment. The exception is to be granted only when it is clearly shown there is no other feasible way to gather information.

Criteria for Considering Exemptions to Prohibitions

Measurement protocols that require exemptions to the prohibitions against structures, installations, and motorized equipment in wilderness areas are not likely to be considered favorably. The criteria for considering exemptions are found in the Forest Service Manual in the following sections:

Structures - 2324.3. This section sets criteria that are intended to limit structures to "those actually needed for management, protection, and use of the wilderness for the purposes for which the wilderness was established." This section also requires documentation of need for structures, schedules for their removal, and sets specific standards for materials and siting.

Research - 2324.4. While "encouraging research in wilderness that preserves the wilderness character of the area," this section requires that research proposals be reviewed "to ensure that research areas outside the wilderness could not provide similar research opportunities" and "to

ensure that research methods are compatible with wilderness values." Further, it requires specific use stipulations in the approval document. Requests for exemptions to wilderness access/user restrictions cannot be based on economic costs to, or the convenience of, the researchers.

Motorized Equipment and Mechanical Transport - 2326. In an effort to "exclude the sight, sound, and other tangible evidence of motorized equipment or mechanical transport within wilderness," this section lists the specific criteria for exemption from prohibitions on the use of motorized equipment and mechanical transport in wilderness.

In all likelihood, then, a request for an exemption is likely to be refused unless it can be demonstrated unequivocally that the data to be gathered under the exemption are absolutely necessary, and all possible alternatives to the exemption have been considered.

In conclusion, the Wilderness Act and the Forest Service regulations require the use of scientific protocols and measurements that protect wilderness values. This means that the measurements either must be easily obtainable within the wilderness by primitive means, or be obtained from representative sites outside the wilderness.

Some Specific Constraints Considered in Protocol Development

The following are examples of specific factors and issues that have constrained and shaped the development of protocols.

1. No guidance is given in the CAA as to how much advance notice the FLM must be given by the permitting authority to allow proper assessment of potential AQRV impacts of a proposed new source of air pollution. Although the FLM may have more than a year, in practice he may have as little as 30 days for conducting this analysis. Thus, FLM may not be free to begin a monitoring study after he is presented with the permit application. To be useful in the permitting process, data must have already been collected under the protocols. Moreover, the data must

have been gathered over a sufficient time period to establish meaningful current conditions of the resource in question.

2. The types of AQRV measurement and analysis that can be performed may be seriously constrained by certain physical and environmental factors in the alpine and subalpine setting. These factors may include weather, season, animal damage, remoteness, and lack of power.

3. The AQRV analyses likely will be constrained by a lack of skilled personnel and funding. In general the protocols call for monitoring efforts that are simple and cheap, use current state-of-the-art methods and equipment, and do not push the boundaries of technology.

4. Because the results of AQRV analyses are to be used in the new source permitting process (and, potentially, in subsequent judicial review) a premium is placed on the reliability of the results and the subsequent ability to make and defend "yes" or "no" decisions concerning whether a proposed source will cause an adverse impact.

5. The ranges of uncertainty in determining potentially measurable changes in AQRVs (or in determining the significance of any given change) as the result of proposed source emissions should be clearly identified and described. The implications of such uncertainty should be described adequately for nontechnical decision makers.

Conclusion

The constraints of the Clean Air Act, the Wilderness Act, management considerations, and the physical and environmental factors seriously limit the types of AQRV measurement and analysis that may be performed in wilderness areas. Guidelines were developed within these constraints to insure realistic and feasible techniques. Some compromises have been necessary between "ideal" or "preferred" AQRV measurement and analysis techniques and those which are deemed "adequate" for management and regulatory purposes. Therefore, the guidelines may be less than "state-of-the-art." Nonetheless, these guidelines and techniques are intended to be scientifically sound and accurate enough for reliable determinations of the current condition of the area's air quality related values.

Atmospheric Environment

Purpose

A major objective of this atmospheric component of these guidelines is to establish a reference for assessing the impact of airborne pollutants on sensitive ecosystems. To meet this objective, this guideline includes measurement methodology for the ambient concentration of certain gases and aerosols, and for the concentration of pollution-related ions in precipitation and snow pack. Dry and wet deposition of pollution-related material can be inferred from these ambient measurements.

Dry deposition fluxes can be computed by multiplying the ambient concentration of the pollutant above a surface by its deposition velocity, which is assumed to vary with land surface type, time of day, season, and several other factors. Meteorological measurements will therefore accompany the ambient concentration measurements. This approach represents a highly empirical parameterization that relies heavily on a relatively sparse data base of dry deposition measurements.

Wet deposition can be estimated by multiplying the precipitation-weighted ion concentration by the total amount of precipitation, the latter measured by standard meteorological means. During the cold season, snow pack measurements may be necessary for both wet and dry deposition estimates.

Because of the difficulties of making aerometric measurements within a Wilderness, one or more sites will be established at the boundary of the Wilderness, where the inflow and outflow of pollution-related material can be monitored. Within the Wilderness area, passive monitoring techniques can be used such as measuring the total amount of precipitation, measuring the total snow pack depth, retrieving representative snow pack samples for laboratory analysis, and establishing a detailed inventory of land surface type.

The proposed protocols will provide estimates of airborne pollution material. Compliance with pollutant regulations or with allowable air quality increments under prevention of significant deterioration (PSD) regulations is not being examined. These guidelines will not of themselves establish air quality baselines for permitting new sources under the Clean Air Act.

The guidelines make maximum use of existing procedures and methodologies that have been, or are being, field tested as part of a national network.

Several critical assumptions have been made during the development of the atmospheric component of the guidelines. These include:

1. Procedures and measurement methodologies to evaluate compliance with existing standards for criteria pollutants are not discussed. The concentrations for gases and particles within a Wilderness area are expected to be well within existing standards. A notable exception may be

ozone; its continuous measurement is therefore recommended at all sites as required for compliance testing. Should the need evolve for compliance testing based on preliminary assessments, taking into account results from model calculations and other efforts, then the methodologies published in the Federal Register by the EPA will serve as protocols.

2. Models can be used for guidance in selecting regionally representative sites.

3. The meteorological and aerometric measurements should be expanded spatially and temporally if the representativeness of these measurements is in doubt. Aircraft sampling over the Wilderness area and vertical profiles for meteorological data are powerful tools for documenting regional air quality.

4. Although large particle deposition results in significant chemical input to ecosystems, we assume that such particles are primarily from local natural sources and hence not man-caused. Thus no measures are suggested at this time.

Warm Season Measurements

Gases and Aerosols

Table 1 summarizes the aerometric parameters that are measured in this protocol. Our knowledge of trace gas and aerosol exchange between the atmosphere and the earth's surface is limited to a small number of gases (mainly ozone, NO_2 , HNO_3 , SO_2 , and NH_3). This guideline suggests dry deposition may be

Table 1.—Aerometric measurements.

Analyte	Measurement method	Time resolution	Quantitative detection limit (QDL)	Desired accuracy
O_3	uv photometry, automatic	hourly	5 ppb	1gr of QDL or 10%
NO_2^1	filter pack (TEA-impregnated filter following Teflon and nylon)	day/night ² (12 hr each) for up to 1 wk average	0.1 ppb	1gr of QDL or 20%
Mass, SO_4	filter pack (Teflon)	day/night ² (12 hr each) for up to 1 wk average	0.2 ppb	1gr of QDL or 20%
Inorganic nitrate	filter pack (Teflon, nylon)	day/night ² (12 hr each) for up to 1 wk average	0.2 ppb	1gr of QDL or 20%
Total ammonia	filter pack (oxalic acid-impregnated filter following Teflon)	day/night ² (12 hr each) for up to 1 wk average	0.2 ppb	1gr of QDL or 20%
SO_2	filter pack (K_2CO_3 -impregnated filter following Teflon)	day/night ² (12 hr each) for up to 1 wk average	0.2 ppb	1gr of QDL or 20%

¹Optional.

²With the option to measure over a 24-hr period only.

calculated from measured ambient air concentrations. Actual deposition is inferred from concentration data and deposition velocities that have been determined for specific gases and surfaces. The following trace materials are measurement candidates:

Sulfur dioxide (SO_2) is a key primary pollutant of concern in Wilderness. Dry deposition of SO_2 , especially to moist surfaces, is considered a major sink, perhaps the major sink of this species. Uptake of SO_2 by vegetation and ecosystems is an acid-producing process.

Nitrogen dioxide (NO_2) is phytotoxic and hence of direct concern in Wilderness. This gas is relatively insoluble in water, but is highly reactive with biological materials. Chamber studies as well as field measurements indicate that NO_2 can dry deposit at moderate rates.

Ozone (O_3) is formed in the atmosphere as a product of reactions involving hydrocarbons and nitrogen oxides. This connection with nitrogen oxides alone establishes its importance to Wilderness. Ozone has been demonstrated to be phytotoxic. Dry deposition is a major sink of O_3 ; ozone is probably the best studied air pollutant for this reason. All of these reasons place O_3 as high priority for measurement.

Nitric acid (HNO_3) is the final product of atmospheric oxidation of nitrogen oxides. It is a strong acid, highly soluble in water. Nitric acid is thought to be dry-deposited at a high rate, governed by atmospheric turbulence. The high acidity of HNO_3 , as well as its role (often the case with nitrogen compounds) as a plant nutrient, establish the importance of characterizing its dry deposition.

Ammonia (NH_3) is not considered a direct pollutant. Sources of NH_3 are principally biological: animal wastes, fertilizer, etc. NH_3 is of interest in the Wilderness area context because it is one of the principal atmospheric bases available to neutralize atmospheric acids. However it can contribute to soil acidification when taken up by vegetation. Reactions of NH_3 with aerosol H_2SO_4 result in gas-to-particle conversion that in turn affects the deposition and fate of NH_3 . Additionally, NH_3 , as an available nitrogen species, is a nutrient to nitrogen-poor ecosystems. Little is known about dry deposition velocities of NH_3 , but they may be large in view of the high solubility of NH_3 at acidic to neutral pH.

Aerosol particles are a prime cause of visibility reduction as well as the means by which acidic material is delivered and hence are of considerable concern in Wilderness. Most of the sulfate and nitrate associated with atmospheric particles is found on particles of 0.05 to 5 micron diameter, as a result of gas-to-particle conversion. Because these particles can travel over long distances (because of their low gravitational settling velocities), they are good indicators of distant pollution sources, particularly of sulfur dioxide.

Wet Deposition (Quality and Quantity)

Table 2 lists the parameters to be measured

in precipitation. Wet deposition is a major pathway for the transport of nitrogen and sulfur compounds to the earth's surface. Wet deposition combined with dry (gases and aerosols) represents total deposition. Thus precipitation quality and quantity is of major importance in determining pollution impacts on ecosystems. Because of the remote location of Wilderness areas from major pollution sources, a significant fraction of the total deposition of pollution-related material will be delivered as "wet" deposition.

Several national wet deposition networks have been in operation for several years. The installation, operation, and subsequent laboratory analyses are well established and are adapted for this protocol. All of the analyses listed in table 2 can be conducted at a central laboratory. The only variables measured at the monitoring site after precipitation collection (or within a few hours driving distance from the monitoring site) are precipitation quantity, field pH, and conductivity.

Meteorological Measurements

To assess total deposition, both wet and dry, a series of meteorological measurements are required. Meteorological variables to be measured at a representative site (outside the Wilderness area) during the warm season include

Table 2.—Summary of analytes, analysis methods, and detection limits for precipitation

Analyte	Method	Time resolution		Quant. detection ¹ limit (mg/l)	Desired accuracy ²
		Warm season	Cold season		
H^+	electrode	weekly ave	accumulation over season	—	0.05 pH units
Total alkalinity	titration	weekly ave	accumulation over season	—	20%
Conductivity	bridge	weekly ave	accumulation over season	—	20%
SO_4^{2-}	IC ³	weekly ave	accumulation over season	0.2	1gr of QDL or 10%
NO_3^-	IC	weekly ave	accumulation over season	0.2	1gr of QDL or 10%
Cl^-	IC	weekly ave	accumulation over season	2.0	1gr of QDL or 10%
NH_4^+	AWC ⁴	weekly ave	accumulation over season	0.5	1gr of QDL or 10%
Na^+	AA ⁵	weekly ave	accumulation over season	0.2	1gr of QDL or 10%
K^+	AA	weekly ave	accumulation over season	0.2	1gr of QDL or 10%
Ca^{2+}	ICP ⁶	weekly ave	accumulation over season	0.2	1gr of QDL or 10%
Mg^{2+}	ICP	weekly ave	accumulation over season	0.2	1gr of QDL or 10%

¹Defined as the minimum value that is likely to be detected by the stated method when applied to actual precipitation samples. This value is larger than the minimum detection limit that is achievable in the laboratory for pure standard solutions.

²Defined as the maximum difference between the measured and true value of the quantity in question.

³Ion chromatography.

⁴Automated wet chemistry.

⁵Graphite furnace/Atomic absorption.

⁶Inductively coupled plasma spectroscopy.

temperature, pressure, precipitation, wind speed, wind direction, surface wetness, and relative humidity. Precipitation quantity is a particularly important meteorological variable; wet acidic deposition calculations are very sensitive to estimated precipitation amounts.

Precipitation data measured at a single Wilderness area station during the warm season cannot be representative of precipitation over the entire area. It is important to consider other mechanisms to collect precipitation data within the Wilderness. Because topography and ground cover vary widely in these areas it is not possible to estimate how many collection points might be required in general. It may be possible to estimate the amount of precipitation over the Wilderness area from these combined data, but the reliability of any such effort will depend upon the intensity and frequency of the sampling. Questions such as sampling design and reliability and representativeness of the data are not addressed in this document.

Wind data are collected at the same location to provide information necessary for understanding the variability in the aerometric and precipitation chemistry data, as this variability often can be attributed directly to sources upwind. Pressure and temperature data are needed for calculating volume flow rates for aerometric samples. Temperature and humidity data may be needed, along with land use data, vegetation cover data, surface wetness, and other parameters, to estimate dry deposition rates. Meteorological data are also useful for modelling studies that may be required in support of data assessment.

The instruments proposed for this Wilderness area program are listed in table 3. The accuracies specified by the manufacturers are noted. This equipment has been field tested and has been routinely used in many monitoring programs. No recommendations are made for a specific manufacturer; other instruments may have equally satisfactory performance characteristics.

Cold Season Measurements

Table 2 lists the analyses to be conducted on snow pack samples. The snow pack provides an accumulation and integration of deposition events of natural and anthropogenic water-soluble and particulate inputs. Total deposition of pollution-related material averaged over the entire cold season (wet and dry) can be estimated for selected sites within the wilderness area, provided that snow melt occurs only during the normal spring melt period and not intermittently during the winter. Because of the inaccessibility of most parts of the wilderness area during the cold season, seasonal total deposition may be the only measurement parameter obtained during this season.

Depending on the accessibility of the warm season monitoring site, measurements of gases and aerosols should continue during winter. The measurement of "wet" precipitation by use of the wet-only sampler depends on the ability of the sampler to operate effectively under existing

Table 3.--Recommended meteorological equipment list, warm season.

Parameter	Measurement Method	Range	Accuracy
Wind speed	Cup anemometer	1-40 m/s	0.2 m/s up to 13 m/s, and not exceeding 0.5 m/s thereafter
Wind direction	Vane	0-540 degrees	1-2 degrees
Temperature	Two element composite linear thermistor	-30 to +50° C	1° C
Relative humidity	Dielectric polymer capacitance	0-100%	2%
Pressure	Capacitance aneroid	600-1100 mb	0.3 mb
Precipitation ¹	Weighing mechanism	0-15 cm	0.01 cm
Surface wetness	Leaf wetness grid	resistance measurement	

¹At sites where a significant fraction of the precipitation is in the form of snow, an Alter-type windshield will be added.

weather conditions. Meteorological measurements should continue throughout the cold season.

Requirements

Sampling Program for Warm Season

In principle, the monitoring sites cannot be located within the wilderness area. The number of required sites depends on the wilderness area under investigation. The equipment measurements detailed here are on a per station basis. A further assumption is that a qualified central laboratory(ies) will be responsible for preparing all required materials (filters, collection bottles, shipment containers, etc.) for the field sites and analyzing the exposed filters and collected precipitation samples. The equipment needs for such a central laboratory are not detailed here, but table 4 presents an overview of the expected concentrations in samples as a function of various analytical techniques available for the analysis of both impregnated filters (from filter pack) and precipitation samples (rain and snow). Table 5 summarizes the instrumentation requirements for the monitoring site. All equipment or support items except the filter pack are readily available from several manufacturers. All equipment and field procedures for precipitation and snow pack samples should be (to the maximum extent possible) identical to existing national or State programs to insure maximum data compatibility.

No standardized equipment for filter pack systems is in use today. Both EPA and EPRI are planning the deployment of filter pack systems in 1987 as part of a nationwide gas sampling network to measure ambient concentrations. The equipment discussion that follows assumes such networks will be implemented, and filter pack equipment (with impregnated filters) or annular denuders will become commercially available for this wilderness area monitoring protocol.

The filter pack air sampling method uses

Table 4.--Expected concentrations of rainwater contaminants, laboratory detection limits for selected constituents in rainwater and filter packs (min. detection level, MDL, in ug/ml, precision in %).

Observable	Typical Concentration Range (ug/ml)								Titration ⁸
	Rural	Remote	IC ^C	AC ⁴	ICP ⁵	AA ³	XRF ⁶	Electrode ⁷	
SO ₄ ²⁻	3.4 ¹	0.8-1.2	0.025/5%	0.3/5%			0.04/2% (S)		
NO ₃ ⁻	2.3 ¹	0.7-1.0	0.015/5%	0.04/5%				0.4/5%	
Cl ⁻	0.64 ¹	0.15 ²	0.007/5%	0.02/5%			0.02/2%	1.8/10%	
NH ₄ ⁺	0.39 ¹	—	0.011/5%	0.005/5%				0.015/5%	
Na ⁺	0.31 ¹	0.085 ²	0.007/5%		0.002/10%	0.002/2%	0.05/2%	6.02/5%	
K ⁺	0.088 ¹	0.02-0.04	0.016/5%			0.01/2%	0.01/2%	0.04/5%	
Ca ²⁺	0.21 ¹	0.2-0.5			0.00007/5%	0.01/2%	0.007/2%	0.02/5%	
Mg ²⁺	0.057 ¹	0.03-0.08			0.00005/5%	0.001/2%	0.04/2%		
H ⁺	0.074 ¹	—						± 0.1 unit	
Total acidity	0.11	—							0.002/3%
Conductivity	0.7 umhos	—							0.1 umhos/<10%

¹Average of 8 sites. MAP3S/RAINE 1982.

²NADP/MIN sites.

³Desert Research Institute Lab results.

⁴Technicon, Inc. specified limits.

⁵Fassel and Knisely 1974.

⁶Assumed 47 mm filter, 5 ml rinse using protocol 5

detection limits as specified by NEA labs.

⁷Orion specific ion electrode, MDL as specified.

⁸Monthly average values from Chan et al. 1983.

selective filters within the filter pack to collect specific pollutants over a 12-hour to 7-day period, depending on protocol. The filter packs are sheltered in a sample head, which is permanently attached on a support pole at a height of 7 meters.

With this pack of sequential absorbing filters, the average concentration (12 hr up to one week) of fine particles (SO₄, NO₃, NH₄) and gases such as SO₂, HNO₃, NO₂, and NH₃ can be monitored. When the airstream is drawn through a size selective inlet, particles of a specified size range can be captured. Various choices exist for the selection of filter media, absorbent, flow meters, and size selective inlets. Although filters are not considered an equipment item, they are discussed because they are an essential part of the system.

Particles. Teflon membrane filters will be used to collect the particles before the air stream encounters other filters. A cyclone is included prior to all filters to remove particles larger than approximately 2 µm, and a short length of Teflon tubing is used as a transition flow reactor for the flow before encountering the filter (Knapp, et al. 1986, Durham, et al 1986). Teflon has been shown to quantitatively pass HNO₃ (Goldan et al. 1983), although nitrate particles collected on the filter may volatilize (Appel et al. 1984). Although these filters are analyzed only for sulfate and nitrate as part of the wilderness protocol, they are selected and sectioned so that more extensive chemical analyses can be performed on them at some later date. (X-ray fluorescence analysis for elemental species might be useful, for example.) This may be useful for visibility considerations.

Nitric Acid and Ammonia. Nylon membrane

filters are used to capture nitric acid (HNO₃). The specificity of nylon for HNO₃ capture has been demonstrated in both laboratory (Miller and Spicer 1975, Spicer et al. 1978) and field studies (Spicer et al. 1982). Nylon does not remove NO₂ or PAN but may absorb N₂O₅ at high humidities. When located downstream of the Teflon filter, it also absorbs any HNO₃ and some of the SO₂ that may be volatilized from the particulate collection. Nylon membrane filters (Nylasorb) have been used to trap nitric acid quantitatively (Spicer 1979). Recently, citric acid coated glass-fiber filters have been recommended for collection of ammonia (NH₃) as a backup in the filter pack system. This allows the collection of any ammonia formed from ammonium nitrate particles collected upstream (EPA 1987).

Nitrogen Dioxide. A glass-fiber filter impregnated with triethanolamine (TEA) absorbs nitrogen dioxide (NO₂). The TEA filter will measure time-averaged low concentration NO₂ (Levaggi et al. 1973, Durham and Ellestad 1984, Knapp, et al. 1986).

Sulfur Dioxide. A K₂CO₃-glycerol impregnated cellulose fiber filter has been shown to be an effective trap for sulfur dioxide (SO₂) (Hugen 1963). A glass-fiber filter impregnated with triethanolamine (TEA) has been used to collect SO₂ (Knapp, et al. 1986).

Various options are available for a system that passes samples of the atmosphere through these filters. For the wilderness area, application of a heated Teflon-coated cyclone that removes particles larger than 2 µm aerodynamic diameter is proposed. Figure 1 illustrates one of these systems (EPA 1987).

The cyclone assembly is housed in an instrument shelter. The cyclone inlet is protected from precipitation but able to sample air directly. A minimum length of Teflon-coated pipe is used to direct the sample streams to the filter packs, located inside the shelter. The mass flowmeters and pump are located in a separate pump box. When replicate sampling is

Table 5.--Summary of basic equipment needs for monitoring site.

Equipment	Time resolution	Man days requirement at site ¹
<u>Warm season</u>		
<u>Precipitation</u>		
Special bucket with lid opened automatically by rain	events averaged over one week	0.4 per week
<u>Aerometric</u>		
Filter pack ² Teflon nylon TEA-impregnated for NO ₂ K ₂ CO ₃ -impregnated for SO ₂ oxalic acid-impregnated	day/night (12-hr schedule) averaged over one week	0.3 per week
Ozone - uv photometry	(1-hr schedule)	0.2 per week
<u>Meteorology</u>		
Wind speed: cup anemometer Wind direction: vane Temperature: resistance thermometer Pressure: capacitance aneroid barometer Precipitation: weighing rain gauge Relative humidity: polymer capacitance sensor	(all 15 min or 1-hr average)	0.1 per week
<u>Support Equipment</u>		
Data logger for meteorology, ozone Triple beam balance pH meter Conductance bridge Calibrator for gas monitor (ozone) Supplies Refrigerator/cooling chest for sample transportation		
<u>Shelter and Tower</u>		
10-meter tower for met instrument and air intake Instrument shelter with AC/heat capable of maintaining temp. Security fence Access road Power access		
<u>Cold season</u>		
<u>Snow Pack</u>		
Standard Federal Sampler	seasonal average collection before snow melt	1 week per station
<u>Support Equipment</u>		
Refrigerator for snow samples Balance Supplies		

¹Exclusive of travel to and from site.²Requires fabrication for samplers, not yet routinely available as an "off the shelf" item.

necessary, a second complete filter pack system and shelter can be co-located.

Filters required for filter pack sampling must meet the following requirements: 1) mechanical stability, 2) chemical stability, 3) low flow resistance, 4) good retention without clogging, 5) low and consistent blank values for the species being measured and those which might additionally be measured, and 6) reasonable cost and availability.

EPA is currently developing protocols for a transition flow reactor (TFR) filter pack as illustrated in figure 1. Interested readers are referred to the authors of this protocol for

further detailed information (Dr. Jack Durham, Atmospheric Sciences Research Laboratory, Office of Research and Development, US Environmental Protection Agency, Research Triangle Park, NC 27711).

Ozone. Ambient ozone (O₃) concentration is measured with a UV photometric type instrument such as a Dasibi Environmental 1003-AH ozone monitor or the equivalent model TECO 49P. The Dasibi UV absorption photometer measures the amount of ultraviolet radiation absorbed by ozone in a sample of ambient air. The quantity of light absorbed is proportional to the concentration of ozone in the air sample. Ozone concentration readings are digitally displayed on the front panel over the range of 0.000 to 1.000 ppm. An analog output of 0-1 VDC also is connected to the data logger.

Gas is continually supplied to the sample chamber by a self-contained pump and handling system. The intensity of the UV beam traversing the sample cell is attenuated in proportion to the ozone concentration in the sample. The signal is electronically processed for presentation by the readout system and output to the data logger. Two reference subsystems provide a high degree of stability by correcting for source intensity, optical path transmittance, and detector response changes. Self zeroing and interference removal are accomplished by comparison of sample and reference readings. If the operating parameters of the analyzer are within specifications, no span or zero drift occurs and the analyzer is self-calibrating.

Cold Season -- Snowpack Sampling

Several standardized tools are available for sampling snow cover. Table 6 summarizes the properties of snow samplers used in North America.

Tests suggest that a sharp "Federal sampler" (or equivalent) is suitable for use in most types and depths of snow cover. Cooperative testing by North American agencies through the Western Snow Conference is continuing in an attempt to develop a standard metric sampler that will provide accurate and repeatable measurements for deep and shallow snow covers (Farnes et al. 1980). Currently, the "Standard Federal" is the preferred choice throughout the western U.S. and Canada. Experience indicates that, in deep snow packs (> 4-5 m depth) with numerous ice lenses, the Standard Federal corer is not sufficiently robust for repeated coring during a single field trip. This is especially true for coring in cold, continental snow packs such as those found in the Rocky Mountain region. In such cases, a McCall corer should be used. Cross-calibration to Standard Federal core sampling efficiency has been reviewed by Farnes et al. (1980).

For very dense, deep snowpacks, a combination of a core and a snowpit may be necessary, since it may be impossible to extract the coring tool (Dozier, pers. comm.). Snow pits also allow much more detailed examination of the snow. They provide the only practical method of determining layer structure, ice lense structure, and snow microstructure available at the present time. Details of snow pit observations are found in Perla and Martinelli (1976) and Jones (1983).

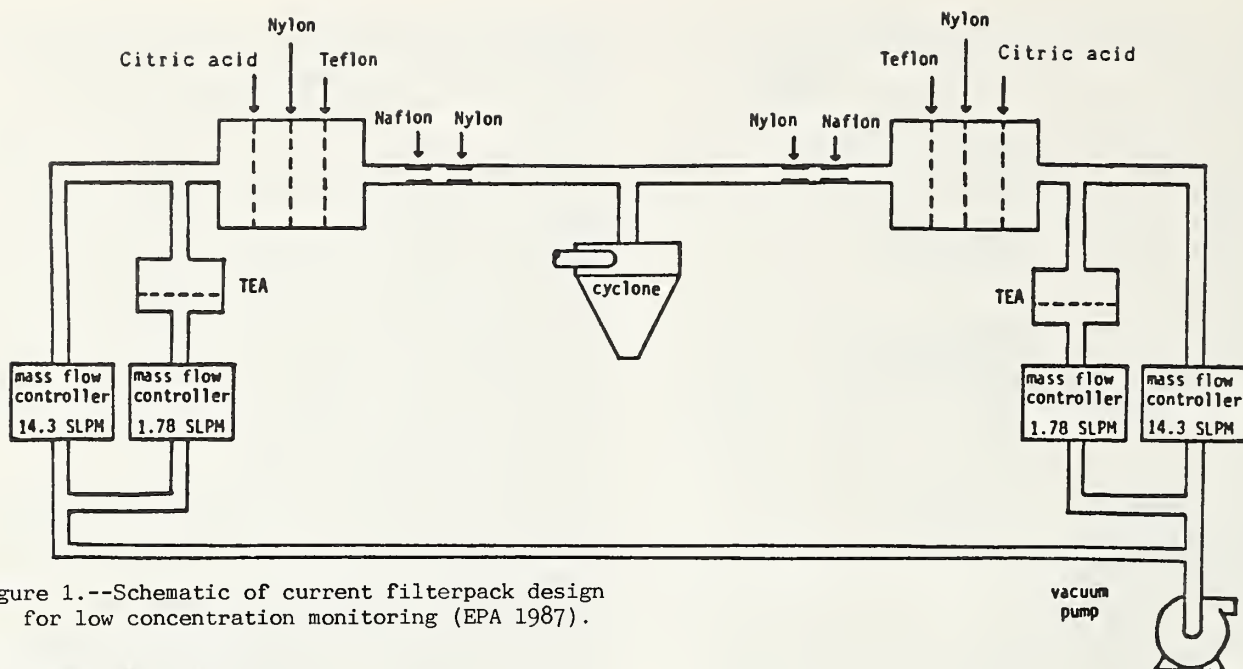


Figure 1.--Schematic of current filterpack design for low concentration monitoring (EPA 1987).

Table 6.--Snow sampler properties.

	Standard ¹ Federal	Federal ²	Bowman ³ L-S	McCall ⁴	Canadian ⁵ MSC	Adirondack ⁶
Material	aluminum	aluminum	plastic or aluminum	heavy gage aluminum	aluminum	glass fiber
Length of tube ⁷ (cm)	76.2	76.2	76.2	76.2	109.2	153.7
Theoretical ID of cutter (cm)	3.772	3.772	3.772	3.772	7.051	6.744
Number of teeth	16	8	16	16	16	None ⁸
Depth of snow that can be sampled (m)	<5	<5	>3.5	>5	1.0	1.5
Retains snow cores easily	yes	yes	yes	yes	no	no

¹Standard sampler used in the Western United States and Canada.

²Identical to "Standard Federal" but has an 8-tooth cutter.

³Cutter has alternate cutter and raker teeth and may be mounted on plastic or standard aluminum tubing. It is more an experimental rather than operational sampler.

⁴Used in dense snow or ice. It is a heavy gage aluminum tube with 5-cm cutter with straight flukes. It may be driven into the pack with a small slide drop hammer producing an icepick effect.

⁵Atmospheric Environment Service large diameter sampler used in shallow snow cover.

⁶Large diameter fiberglass sampler commonly used in Eastern United States.

⁷Most snow samplers in North America use inches and tenths as their basic units of measurement. Values in this table are corresponding metric equivalents.

⁸Stainless steel circular cutter edge or small teeth.

Note: A special sampler is needed for snow sampling if snow is analyzed for trace metals.

Whether or not the increased information is worth the increased work of digging pits depends on the intended use of the information.

Field Procedures

Sampling Site Selection Criteria -- Warm Season

Regional considerations.--Because of the

difficulties in operating monitoring sites within the wilderness area, "representative" locations will be chosen for sites at the periphery of the area. "Representative" in this context refers to the climatology of the region and to the synoptic scale air mass flowing over the wilderness area. Both of these overall meteorological parameters should be assessed in conjunction with man-made pollution sources in a roughly 500-mile zone surrounding the wilderness area to determine approximate locations for potential monitoring site(s). Ideally, such an assessment should yield monitoring site(s) that can characterize the flow of pollution-related material into and out of the wilderness area. The number of monitoring sites must be established on a case-by-case basis, and obviously depends on the size of the wilderness area, the complexity of terrain, the acceptable level of uncertainty, etc. Determining an appropriate number of sites is not an easy task. TAPAS models (Fox, et. al., 1987) are available to aid in this task.

Local considerations.--The most important criterion is the availability of electrical power, because most of the atmospheric samplers require at least 110 V electricity. Within the constraints set by the availability of power, the sampling site should be as close to the remote area of interest as possible. The temporal variation of atmospheric concentrations of interest is probably much greater than the spatial variation, particularly in background locations; however, very little data are available to confirm this speculation.

The selection of the atmospheric sampling site also should depend on potential local sources of pollution. Potential local sources include home chimneys, vehicular traffic, auxiliary diesel generators, and local industrial activities. Seasonal changes in activities producing potential pollution also should be noted.

Because of the size of some of the equipment and the need for servicing on a year-round basis, the site should have reasonable access: one should be able to drive close (0.5 km) to the site during various weather conditions. Ideally, the site should be located where year-round staff are available to service the equipment and change the sampling heads.

The site should be protected from animals and unauthorized human entry. The first line of defense is to locate the site out of normal view. Other ways to protect the site include fencing, signing, or locating at a site with a permanent resident on officially protected property such as a ranger station, a university field station, etc. Experience indicates that the most effective protection of a site is to keep it out of everyday view.

Ideally, the site should have a complete ground cover to minimize resuspended materials and dust from the local area, but should never be under or near overstory vegetation. As a rule of thumb, the diameter of the opening should be about 10 times the average height of the surrounding overstory vegetation. The site should be located so that sampling will reflect, as accurately as possible, the chemical constituency of air masses of fairly large circulation.

Because many sampling sites will not have all of the desirable attributes, some compromises must be made. To evaluate tradeoffs, a systematic decision-making process should be used. For example, site criteria are divided into those which must be met, and those which are desirable. Ranking is based first on "musts", then "wants"; a final decision is made by a group of experts in atmospheric sampling.

Site criteria are summarized in table 7. The instruction manual issued by NADP (NADP 1984a) provides further information regarding the establishment of a wet deposition site using the wet/dry precipitation collector.

Sampling Site Selection Criteria for Snowpack -- Cold Season

Total deposition of pollutant-related material accumulated in snow over the entire cold season will be monitored at sites within the wilderness area. The number of snow cores to be sampled varies with the size of the wilderness area, the extent of ecologically sensitive regions, the complexity of the terrain, and other factors, but a minimum of five samples should be taken at each site. These should be selected to collect maximum deposition.

The snowpack should be sampled at maximum accumulation, but before spring melt starts. These ideal conditions are not always met. The Cascade and Sierra Nevada Mountains have a warm snowpack with temperatures usually near 0°C (Smith 1974). Because of air temperature variations, some melting of the snowpack may occur during the winter, and depending on temperature conditions, rain may fall on the snowpack and percolate through it. Such percolation, if it continues through the entire depth of the snowpack, can leach soluble material from the snow in concentrations disproportionate

Table 7.—Site selection criteria for representative aerometric station (warm season) outside of wilderness area.

<u>General criteria</u>	
1.	The site(s) should be selected to give samples representative of the wilderness area.
2.	The site(s) must be accessible during the warm season in all weather conditions on a daily basis.
3.	The site(s) must be located in an area secure from damage by animals or vandals.
4.	The site(s) must be serviceable by line power and either have a suitable equipment shelter or have room for a suitable shelter.
5.	Sampling site(s) should be situated no closer than 20 km from areas enclosing combined sources larger than 10,000 tonnes/yr SO _x or NO _x .
6.	Sampling site(s) should be located at least 5 km from population centers greater than 5,000, at least 10 km from population centers greater than 50,000.
7.	All candidate sites must appear to meet the detailed selection criteria listed below.
8.	The landowner or custodian must be in full agreement with the intended use of the site (including any restrictions on access or use such as limitation on development) and willing to grant the access and space needed to fulfill the sampling requirement for the lifetime of the network.
<u>Specific criteria</u>	
1.	All large objects that might contribute to the contamination of precipitation samples must be farther than two times their height from the sample collector or fall below a 30 degree elevation angle when viewed from the collection point.
2.	Small objects, such as vegetation or fences, that are of comparable height to the height of the precipitation collector opening must either be farther than two times their height from the collector or be at a distance equal to the height of the collector opening—whichever distance is greater.
3.	Whenever possible, the precipitation sample and all intakes to aerometric monitoring equipment must be located a minimum of 250 meters from all public roads or other routing mobile sources of atmospheric pollutants.
4.	All sampling sites should be located a minimum of 250 meters from any fertilizer storage areas, feed lots, fuel storage areas, stationary internal combustion engines, or other similar sources of potential contaminants.
5.	Sources of dust, such as construction areas and tilled farm lands, should be avoided whenever possible. If this restriction cannot be met, these sources should be kept at least 250 meters from the sample locations.
6.	All possible efforts should be made to locate monitoring sites on level, naturally vegetated land or in grassy areas. No site should have a slope greater than 20 degrees from the horizontal.
7.	All sites must be accessible by vehicle.
8.	All sites must be located outside the wakes of buildings, trees, or abrupt changes in terrain.
9.	All sites must have clean, temperature-controlled working area set aside for sample processing. The area should be dedicated to the handling of precipitation samples and it must not contain any potential contaminants.

to those in the snowpack (Johannessen et al. 1980). In addition, atmospheric conditions under which the snow was deposited, the degree and type of metamorphism the snow has undergone, and the intensity of rain and/or melt events all can influence the rate at which impurities can be removed from the snow (Shockey and Taylor 1984). Thus, the snowpack cannot be assumed to accumulate and hold all atmospheric deposition during the life of the snowpack.

To lessen the possibility of rain and melting impacts, sampling sites should be located above the freezing level for the particular geographic region under consideration. Whenever possible,

the sampling sites should be located in the southwestern part of meadows or in open areas where shading minimizes surface melting from solar radiation. At lower elevations, the temperature of the snowpack may reach 0°C and therefore endanger its integrity. Selective leaching of ions from the snowpack can be identified by setting out waterproof boxes of about 2 X 2 m and lined with polypropylene plastic in the fall. Snow cores collected outside the boxes can be compared with cores plus melt water from inside the boxes during the later winter sampling period.

Sample Collection Procedure -- Warm Season

Filter pack.--Every seven days (when samples are removed from the precipitation collector), the filter pack is removed and a new filter pack is installed. The following is a preliminary description of the procedures to be followed. The final protocol will depend on the selection made for the national programs.

1. Check the flow rate as indicated on the sampler control module digital readout. Obtain the actual flow rate from the calibration sheet that corresponds to the indicated value from the sampler. Record this value as the "OFF Flow Rate" in the log book and sample record sheet.
2. Note the time on the data logger display. Record this time as the "OFF time" in the log book and sample record sheet.
3. Lower the sample head by releasing the cam lock at the base of the tower and slowly feeding out the line tied to the tower upright.
4. Remove the filter packs by pulling up on the quick-connect fittings collar. Place the filter packs in zip lock bags.
5. The quick-connect fittings seal themselves off when no filter is installed: this will check the system for leaks. After one minute, check to see that no flow is indicated on the control module digital readout.
6. Install the new filter packs by pushing them into the quick-connect fittings in the base plate. The "sample" filter pack should be installed in the fitting marked SAMPLE and the blank filter pack in the fitting marked BLANK.
7. Raise the tower by pulling on the line attached to the end of the tower upright. Secure the upright into the tower base plate and engage the cam lock.
8. Note the time indicated on the data logger display. Record this time as the "ON time" in the log book and sample record sheet.
9. Check the flow as indicated on the control module digital readout. If necessary, adjust the flow to the value corresponding to a flow rate of 1.5 liters per minute from the sampler calibration sheet. Record this value as the "ON flow rate" in the log book and sample record sheet.

Filter pack handling and shipment.--After removal, the complete filter pack is sealed on both ends with plastic screw caps, placed inside a zip lock bag, tagged, and shipped inside a padded box to a central analytical laboratory. The following information should be recorded in the station log book and on the sample identification tag, which will be attached to the

zip-lock bag containing the filter pack: filter number, side ID number, start date and time, and stop date and time.

Standard Operating Procedures (SOPs) have been developed for all phases of the field sampling collection by EPA and Atmospheric Environment Service, Canada.

Precipitation.--An SOP for the measurement of wet deposition exists for all major national networks. The SOP for NADP/NTN will be adopted here. Operational steps including bucket changing and weighing, sample storage, field laboratory analysis (pH and conductance measurement), shipment and maintenance are detailed in the NADP site operation manual (NADP 1982).

In summary, the NADP/NTN protocol is the following:

1. An aerochem Metric Model 301 wet/dry precipitation collector collects precipitation samples, and a Belfort recording rain gauge measures daily precipitation amounts.
2. Samples are collected weekly.
3. The sample is weighed at the site to determine total precipitation volume. The soil-contaminated portion of sample is carefully removed.
4. A 20 ml aliquot is removed for laboratory and pH measurements.
5. A form is filled out by the site operator describing the sample and the collection characteristics (see fig. 2).
6. The sample is mailed in the sealed collection container along with the sample reporting form to a central laboratory for analysis.

Because of the dilute nature of precipitation samples, handling procedures must be followed carefully to prevent contamination. These procedures are presented in detail in the NADP/NTN manual. This plan is adopted for the operation of the monitoring sites, with the exception of those sections which refer specifically to liaison with the NADP/NTN Central Analytical Laboratory (CAL).

Ozone.--SOPs exist for all aspects of ozone measurement, calibration, and preventive field maintenance. They are detailed in, and part of, the owner's manual supplied by the manufacturer (either TECO or Dasibi). The Mountain Cloud Chemistry Standard Operating Procedures can be used for further guidance.

Snowpack Collection Procedure -- Cold Season

The snow sampler is lowered vertically into the snowpack with a steady thrust downward. A small amount of twisting aids in driving the tube and cutting thin ice layers, but considerable force and twisting of the sampler with a driving wrench may be required to penetrate hard layers of ground ice. Penetration to extract a soil plug helps to prevent the loss of the snow core from the tube, and a trace of soil or litter in the cutter indicates no loss has occurred. A quick comparison of the length of the snow core against measured snow depth will show whether a complete core has been obtained. The amount of compaction of the snow core during sampling will depend on snow conditions. If the snow core

Snow Course No. _____

Name _____

Sampler _____ Date _____

Station No.	Snow Depth cm	Weight Tube & Core	Wt. Tube Only Before Sampling	Water Equivalent cm	Core Length cm
Total					
Average					

Checked _____ Date _____

a.m. _____ p.m. _____

SNOW SAMPLING: Began _____ p.m. Ended _____ p.m.

Sampling Conditions _____

(Please check items descriptive of present conditions)

Weather at time of sampling: Temp. _____ °C

_____ Clear	_____ Snowing
_____ Partly Cloudy	_____ Blowing
_____ Overcast	_____ Freezing
_____ Raining	_____ Thawing

Snow Conditions at Snow Course

_____ Crusted-supports man on skis/snowshoes.

_____ Breakable crust-breaks under man on skis/snowshoes.

_____ Snow soft and powdery-not sticky.

_____ Snow soft and wet-sticky.

_____ Snow samples obtained easily.

_____ Snow samples obtained with moderate difficulty.

_____ Snow samples obtained with extreme difficulty.

_____ Ice layer on ground. How thick? _____ cm

_____ Ground frozen under snow.

_____ Ground not frozen under snow.

_____ Ground dry under snow.

_____ Ground damp under snow.

_____ Ground wet (saturated) under snow.

General Snow Conditions

What elevation is snow-line generally? _____ m

Is snow melting on north and east slopes? _____

Is snow melting on south and west slopes? _____

How many centimetres of fresh snow at snow course? _____ cm

Is there evidence of saow-slides? _____

Weather conditions of past month

_____ generally overcast and stormy.

_____ generally clear and cold

_____ generally clear and melting.

REMARKS: _____

preserved, and bottled.

Because low, near-detection-limit concentrations of solute are expected in the snowpack from remote regions, extraordinary care must be taken in sampling, processing, and analysis, as well as in collection of many samples, if a valid picture of total deposition is to be obtained. Such standard operating procedures must be developed as part of a quality assurance plan. The procedures for analysis of the melted snow are analogous to those used for precipitation samples.

Support Needs

Data Collection from Continuous Monitors

Measurements made by continuous monitors are collected on a data logger at each site with back-up by strip chart recorder. The logger should be a Campbell Scientific Model CR21X/L or equivalent. The collection of continuous data is designed to: 1) compute accurate averages or sums by regular sampling of the data channel, 2) allow checking of data on a regular basis to spot deviations from expected operation, and 3) retrieve the data efficiently.

The data acquisition system is illustrated in figure 4. One-hour averages (1-hr averages) are computed in the data logger from scans made at 5-second intervals. The variables scanned are wind speed and direction, temperature (ambient and shelter), relative humidity, pressure, precipitation amount, and ozone concentration. Status channels will indicate when calibrations or zero/span checks occur, position of the lid on the precipitation bucket, and site service by a door alarm (checked to assure that routine site visits are being performed by the site technicians). The averages are stored in the data logger and on magnetic media for later retrieval. The data are available for inspection and retrieval both on-site and remotely by telephone if a telephone link is conveniently available.

Flags will be placed on variables that have yielded less than 200 valid observations for a 60-minute period because this average is considered potentially invalid. Magnetic media will be collected on a weekly basis (or daily by telephone polling if available). Strip charts serve as the final backup if the data logger should fail.

Strip charts will be changed every 2 weeks and archived for referral as needed. Strip charts are necessary if compliance with standard QA/QC procedures are considered essential. The polled data should be examined by experienced personnel to detect any instrument problems and suspect data that need to be checked or validated at the site. The data should be processed at a designated processing center and checked for range validity, rate of change, and other automatic checks programmed into the data archive system. Flags are assigned to suspect data. All flagged data should be examined by an experienced data technician. The technician reviews the magnetic media or strip charts as necessary to validate questionable data. The data are

Figure 3.--Format for recording snow survey information.

contained in the following SOP's (U.S. EPA):

1. EMSL/RTP-SOP-QAD-531, Extracting and Analyzing Dry Deposition Samples, May 14, 1985.
2. EMSL/RTP-SOP-QAD-503, Analysis of Anion Samples by IC, January 30, 1985.

Precipitation

All sample aliquots arrive at a central laboratory in special containers on a weekly basis. SOPs exist for all phases of analysis and quality control. This wilderness area protocol includes the collection and analysis procedures developed by the Illinois State Water Survey and outlined in Peden et al. (1986).

Snowpack

Samples should be analyzed at a central laboratory. To ensure uniform handling, the melting, filtration, and bottling processes should follow strict protocol (Shockey and Taylor 1984). During melting, the overall temperature of the sample should never exceed 4°C. This procedure will minimize any bacterial deterioration of the nutrient constituents. Immediately after thawing at the central laboratory, the samples should be filtered,

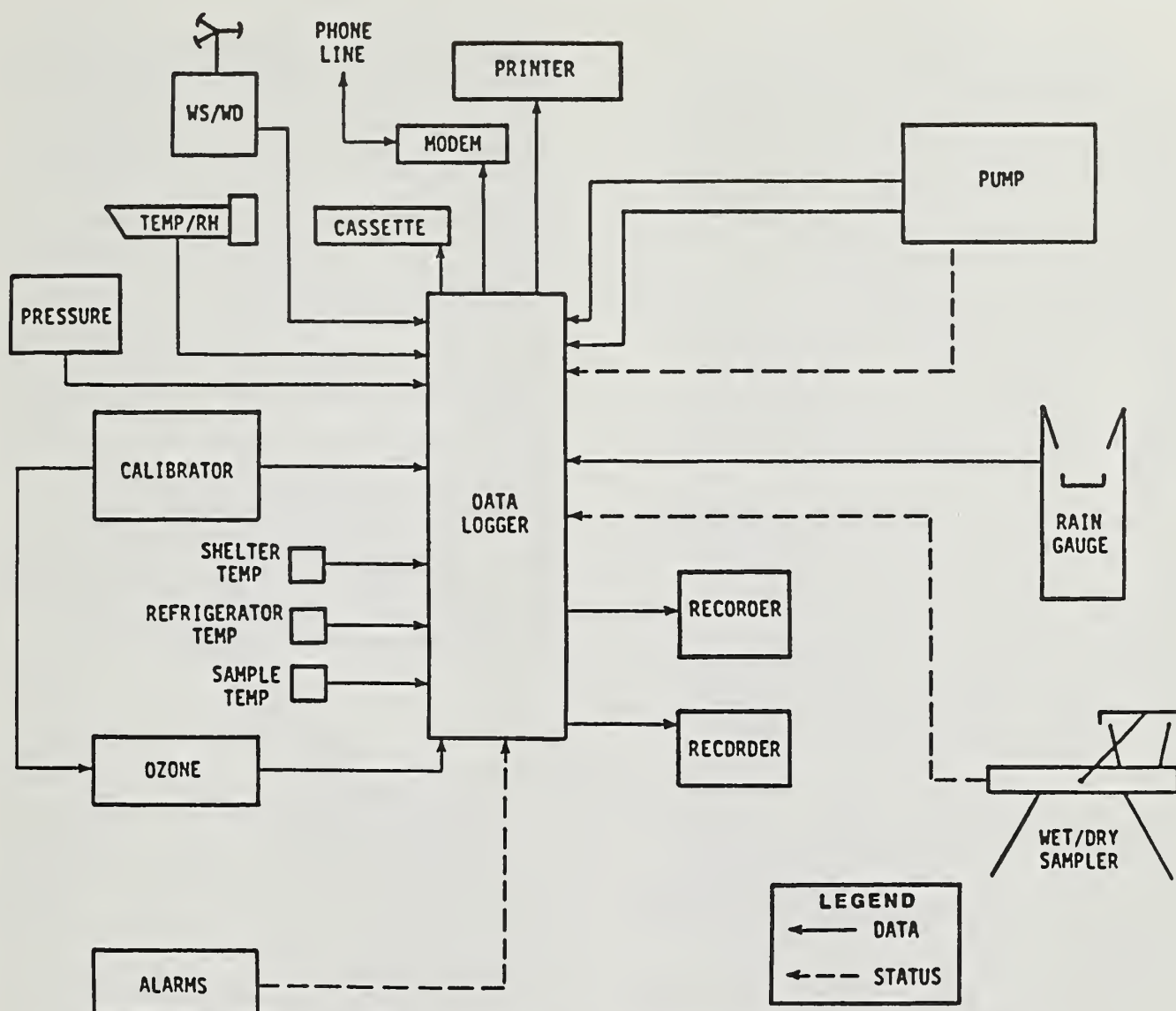


Figure 4.--Schematic of data logging for meteorological and associated measurements.

summarized each month. Quality control is achieved by checking in the field and at the central location. Protocols for QA/QC are available from several field programs.

Quality Assurance

The aerometric, meteorological, precipitation, and snow core data collected by the site personnel should be of a quality consistent with the requirement of impact assessment. Archiving this goal will require a well-conceived quality assurance plan and rigorous adherence to this plan throughout all operational phases of wilderness measurement (NADP 1984b).

Quality assurance can be divided into two types of activities: quality control and quality auditing.

Quality control consists of a set of

mandatory procedures to be followed during the design, collection, and analysis phases of a measurement program. These procedures are designed to insure that the data from the program meet a predetermined set of performance criteria. Quality control activities also provide the information needed to determine the uncertainty in the measurements, i.e., precision and accuracy. Quality control is therefore an ongoing activity performed by the persons actually making the measurements.

The performance of instrumentation and laboratory procedures may be evaluated by comparison with NBS-traceable standards or by the analysis of blind samples. The performance of data processing procedures is tested by independently processing representative sets of measurements by an auditor. Whenever possible, existing QA/QC protocols and SOPs are to be used.

Data Analysis

The monitoring protocol outlined for the wilderness area provides aerometric and precipitation data sets with known accuracy and precision. The accuracy and precision of analytical measurements of air or precipitation samples are evaluated, in principle, in the following manner: 1) accuracy is determined by analyzing EPA and NBS reference samples, unknown reference samples, and spiked samples; 2) precision is determined by analyzing replicated filter or precipitation samples.

The aerometric measurements are reported as concentration in parts per billion (ppb) by volume and in micrograms per cubic meter ($\mu\text{g}/\text{m}^3$), averaged over a time period of seven days. (The protocol is still open as to the sampling mode, i.e., separate day-night samples averaged over one week or one week total average.)

The precipitation measurements (warm season) are reported as concentration in micromoles per liter ($\mu\text{mole}/\text{l}$) averaged over the weekly sampling period. The total precipitation volume accumulated during one week is reported in milliliters (ml). Precipitation amount is recorded separately by the rain gauge as millimeters per day. The snowpack samples are reported as concentration averaged over the entire accumulation time. The total amount of snow accumulated is presented in snow depth, water equivalent, and total volume of water (liters).

From these primary data, one can derive dry and wet deposition data. In addition, the air quality at the boundary of the wilderness area can be established. Air quality within the wilderness area can be estimated by combining the locally measured meteorological parameters with the synoptic scale air flow obtained from standard weather stations.

Concern over the deposition of acidic substances has led to an awareness of limitations in the current ability to monitor dry deposition. At present, relatively few programs are designed to produce dry deposition flux estimates, in contrast to the existence of several networks that produce wet deposition fluxes. The delay in setting up dry deposition monitoring networks is due primarily to the scientific uncertainty of the necessary measurements. No unequivocally accepted method exists for monitoring dry deposition.

Because it is difficult to measure fluxes at the surface itself, dry deposition rates are usually inferred from data obtained in the air above the surface. The critical assumption in this approach is that fluxes measured above the surface are the same as those at the surface, an assumption that depends on the homogeneity of the surroundings.

The deposition velocity, v_d , if known, provides a convenient method for deriving the deposition flux, F , from measurements of concentration in air, C : $F = v_d C$. This calculation is the basis for the inferential or "concentration-monitoring" method. However, the deposition velocity is not fixed for each

pollutant species and surface of interest. In reality, values of v_d are site-specific and time-varying. For this reason, knowledge of the land use and vegetation cover within the wilderness area is essential to associate "appropriate" situation-dependent deposition velocities with the measured, ambient pollutant concentration.

Since the air quality parameters have been measured at another location (at the periphery of the wilderness area), the dry deposition flux as derived in this protocol can only be used as a rough guideline to indicate the influx of pollutants. As a rough guess, the dry deposition fluxes estimated on the basis of this protocol may be accurate only to a factor of two, whereas the concentration values are significantly more precise.

On the other hand, wet deposition and total deposition (snow pack) may be obtained with uncertainties less than 50%, particularly if local precipitation amount is known. Wet deposition is derived as the product of concentration and rainfall amount (warm season). Total deposition accumulated over the cold season is obtained directly from snow depth (water equivalent) and measured concentration of pollutant material in the snow pack.

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Visibility

Visibility (including site visual range, contrast, color, plume blight) in Class I areas is protected under the provisions of the Clean Air Act of 1977, which stipulates that the visibility within Class I areas is not to be degraded and, if possible, is to be brought back to pristine levels. Only visual scenes within Class I area boundaries are protected; "integral vistas" are not protected.

Visibility measurements can be made by several techniques. Since monitoring equipment is not permitted within Forest Service Wilderness boundaries, the Forest Service has adopted the policy of monitoring visibility from locations adjacent to the boundaries. It is assumed that the measurements taken from the nearby site looking into and across the Wilderness are representative of the Class I visual air quality.

A primary goal of visibility monitoring is to quantify how well the image forming information in a vista is transmitted through the atmosphere to an observer some distance away. This requires an understanding of atmospheric extinction (the scattering and absorbing properties of the atmosphere that influence the transmission of light).

Three primary operational electro-optical monitoring techniques are available: integrating nephelometers (Charlson et al. 1967); teleradiometric techniques using natural targets (Malm and Molenaar 1984, Johnson et al. 1985); and transmissometers (Malm et al. 1986, Malm and Tombach 1986). Each method has advantages and disadvantages. For monitoring near wilderness areas where access and manpower are limited and power is generally unavailable, the most successfully applied technique has been photography. Photography has therefore been selected as a practical and economical measurement method.

Transmissometry techniques are currently planned for several Forest Service Wilderness areas as part of the IMPROVE program (Interagency Monitoring of Protected Visual Environments, Joseph et al. 1986). However, current transmissometer systems are experimental and have power, data collection, installation, cost, service, and logistics requirements that make them impractical at most wilderness sites.

Photographic Visibility System

The photographic technique was first proposed by Steffans (1949) and was later refined by Hoffer et al. (1982) and Johnson et al. (1985). Photography offers simplicity and economy in data acquisition with the added advantages of 1) quality assurance of the measurements during data reduction and analysis, and 2) a 35mm slide archive available for future analysis and reference.

The primary electro-optical measurement of target/sky horizon contrast is made by

microdensitometric analysis of the 35mm slides. This technique emulates teleradiometer measurements. The technique is an indirect measurement of the visual air quality because it depends on the film media to accurately depict visual conditions. Sampling is limited to daylight hours.

The color slides can provide the following information:

1. The general condition of the sky and terrain features.
2. The relative color of the sky and terrain features, as well as the presence of layered or uniform haze.
3. A target/sky horizon contrast that is reducible to standard visual range under optimal conditions.
4. Slide archives that provide an easily interpreted and relatively permanent visual record of conditions within the wilderness.

System Components

A primary photographic monitoring system includes the following components:

1. Rugged, reliable 35mm camera body with automatic film winder. The camera's automatic exposure meter must be designed so that it is on only during the actual time of exposure and not continuously operating.
2. 135mm lens with UV filter.
3. Databack capable of imprinting the day and time the exposure was taken on the film.
4. Battery powered programmable timer capable of triggering the camera at least three times per day.
5. The complete system must be able to be housed in a small, stand-alone environmental closure, and operate within the ambient temperature range of -30° to 130°F unattended for at least 10 days.



Figure 5.--Field installation of automatic photographic visibility monitoring used at many Forest Service and Park Service sites (photo courtesy of Air Resource Specialists, Inc., Fort Collins, CO)

A commercially available system (from Air Resource Specialists, Inc.) that meets all of the above criteria is shown in figures 5 and 6. Systems are currently operating in over 25 Forest Service sites. A variety of camera configurations can be fabricated to meet specific site requirements. For example, some existing Forest Service sites operate dual camera systems that take two exposures per day and are serviced monthly.

Photographic Siting Criteria

The overall configuration of the monitoring site depends on the characteristics of the site and target. In most cases, the site will be in an undeveloped location with a quality view. The location should be reasonably accessible and secure year-round. The monitoring view should be selected by personnel experienced in photographic exposure techniques and familiar with the practical aspects and limitations of slide microdensitometry. The monitoring site and target should be selected so that as much of the sight path as possible runs through the wilderness.

The view must contain at least one horizon visibility target with as many as possible of the following characteristics:

1. Large--subtend at least 0.1 degree of solid angle (approximately 20% of the size of the full moon.)
2. Easily identifiable on topographic maps of the area.
3. Dark--preferably covered with coniferous vegetation.
4. Distance--preferably in the range of 40% to 60% of the expected standard visual range. General guidelines are: 30 to 70 kilometers in the western U.S.; 10 to 40 kilometers in the eastern U.S.
5. Number of targets--at least one quality target is required; two or three targets at various distances are preferred.
6. Elevation angle--the site and target should be at approximately the same elevation.



Figure 6.--A closeup view of photographic visibility monitoring enclosure (photo courtesy of Air Resource Specialists, Inc.).

The observer-target elevation angle should be within $\pm 1^\circ$.

7. Targets should be located in the center of the camera view finder (center 30% of the slide).

8. For evaluation of regional air quality, the observer-target sight path should not be affected by local sources of visual air pollution.

9. Target should be selected to be as free of snow during the winter months as possible. Standard visual range values cannot be calculated for snow-covered targets.

10. Avoid exceptionally bright or dark foreground objects that would adversely affect the camera's ability to accurately meter the monitoring view.

11. Sun angle--it is best to orient the target to avoid the sun shining directly into the lens.

System and Operation Costs

System and operational costs depend on site and sampling requirements. The approximate equipment cost for a single camera site, fully outfitted to include 35mm camera, 135mm lens, UV filter, databack, programmable timer, batteries, environmental enclosure, internal locks, sunshield, monitoring hardware, mounting post, tripod head, cabling, documentation chart, instruction manuals, and lens cleaning supplies, would be about \$2,100.

Operational costs depend on the sampling frequency and analytical services. An average cost of contracted services that includes all film, film processing, data analysis, reporting, and archiving is \$5,250 per year (3 photographs per day, 365 days per year). For first-time sites, a one-time site initialization charge of approximately \$1,000 is also charged to cover the costs of preparing site specifications and performing inherent contrast analyses. On-site servicing by local personnel to change film and verify system performance is required every 10 days, and on an average amounts to two to three man-weeks per year including travel time.

It is also suggested that sufficient backup equipment be maintained to ensure continuous network operations.

Field Service Procedures

Routine operations and sampling.--Local personnel will serve as the site operators, and will be responsible for the routine operation of the camera systems. Automatic cameras will take three photographs per day at 0900, 1200, and 1500 local time. Kodachrome ASA 25 color slide film will be used. This film was chosen for its fine grain and excellent color reproduction qualities. For consistency, all film will be developed at the Los Angeles Kodak laboratory. Photographs will be taken using the automatic exposure capabilities of the camera.

At many sites, access limits monitoring to snow-free periods. A number of existing Forest Service sites currently operate for limited periods, such as from late June or July through September.

Site visit/servicing protocols.--Film should

be changed every 10 or 11 days, based on three shots per day and 36-exposure film rolls. A site visit by the field operator will generally include the following:

1. General site/system inspection
 2. Remove camera; remove and replace film (fill out ID label)
 3. Inspect and clean camera lens and box window
 4. Check batteries and databack
 5. Photograph film documentation board
 6. Replace and align camera
 7. Check camera and timer settings
 8. Complete Visibility Monitoring Status Assessment Sheet
 9. Close and lock camera shelter
 10. Mail film and Status Assessment Sheet
- Detailed protocols and maintenance procedures for camera systems have been applied throughout existing Forest Service networks for several years.

Collection, reduction and analysis of photographic data.--The major steps in the handling of photographic data are summarized in figure 7.

All film collected at the sites must be mailed as soon as possible to a Central Processing Facility. All rolls will be logged and forwarded to Kodak for processing. All returned slides will be identified by a site code and consecutively numbered. Any missing or inconsistent samples will be noted and corrective action taken.

For qualitative analysis, the condition observed on each slide will be assigned an identification code. These codes identify weather conditions, observed hazes or plumes, and visibility target illumination conditions. Appropriate qualitative summaries can be prepared from these codes. For example: In 20 percent of data the visibility target is obscured by clouds; layered hazes were observed on 30 percent of 0900 observations.

The basis for quantitative analysis is the measurement of the contrast (in the 550 nm wavelength) between and sky and selected terrain horizon features. This contrast measurement can be reduced to yield a standard visual range value in kilometers. This quantitative measurement is related directly to the site path between the observer and the target. Only the conditions within the path are quantified in this type of analysis.

Reporting.--The results of qualitative and quantitative analyses can be reported in a variety of formats. Most results will be summarized by monitoring season. Example report products could include:

- Site specifications summary, including: site and target constants data, and data collection statistics summaries.
- Qualitative slide condition code summary and statistics.
- Slide and scene contrast listing for each slide.
- SVR listings for each day, time, and target as well as 0900, 1200, and 1500 daily geometric mean SVR.

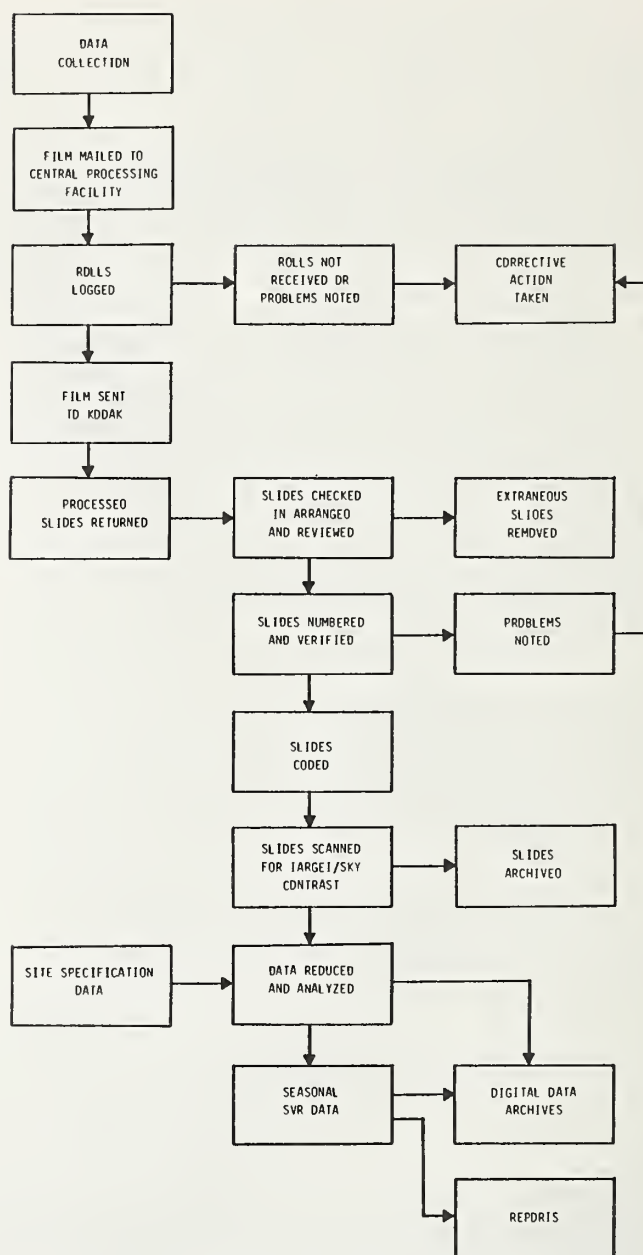


Figure 7.--Steps in the handling of photographic data.

- Monthly plots of daily maximum, minimum, and geometric mean SVR.
- Seasonal standard visual range summaries, statistics, and plots.

All original slides will be archived by site in a Central Processing Facility. All qualitative and quantitative results will be archived in both digital and hard copy formats.

Quality assurance.--All applied procedures will follow fully documented quality assurance procedures. Procedures have been established and operationally applied to account for: film quality; film handling, processing, archiving, and storage; camera operation; scanning; data handling; analysis; and reporting.

Transmissometer Measurement System

Transmissometers are a direct method of measuring atmospheric extinction. Transmissometers consist of a constant-output light source transmitter and a computer-controlled photometer receiver. The two individually housed components must be separated by a line of sight distance of approximately .5 to 10 km, depending on the average extinction coefficient. The irradiance at the 550 nm wavelength from the transmitter can be determined by measuring the light loss from the transmitter to the receiver. Data are collected on logging systems and strip chart recorders.

Several transmissometer installations are planned for Forest Service wildernesses as part of the IMPROVE program. These initial experimental installations will provide further insights into the practical application of transmissometry for monitoring visual air quality in wildernesses. The initial experimental systems are costly to purchase and install. Power can be provided by solar panels at some sunny locations; line power will be required at the receiver at many sites. Both ends of the transmissometer must be serviced weekly by field operators. Trained technicians must visit the site to replace components and calibrate at least every six months.

Siting transmissometers near wildernesses may be difficult since neither end of the system can be installed in the wilderness. Sight paths must generally be elevated to reduce the effect of turbulence caused by surface heating on the light beam.

The advantages of the transmissometer are that the system directly measures atmospheric extinction, both day and night. Continuous measurements can be averaged for selected sampling periods. Disadvantages include high cost, power requirements, sheltering, installation, and servicing logistics. In general, it is recommended that camera systems be operated along with the transmissometer to correlate measured extinction with visual conditions, and as a quality assurance reference.

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Soils and Geology

Purpose

Soil functions in the ecosystem in roles that are important to the productivity and diversity of the terrestrial and aquatic biota. In addition, it has a self-contained biota, and is an efficient trap or collection system for many atmospheric contaminants. A careful description and a set of quantitative measurements of the soil are essential to estimating the sensitivity or stability of the ecosystem, and to determining its response to atmospheric input. The goals of this section are to provide a guide in selecting areas to sample, and to suggest methods for use in the field and laboratory to accomplish the following:

1. Characterize the soil-geologic resource, and evaluate its sensitivity to internal change and its ability to buffer the aquatic system. This information will be used to assist in evaluating the susceptibility or vulnerability of the soils to change due to changes in air quality.

2. Determine the present condition of soils in terms of pH, nutrient ions, metal load, etc. as a reference value to measure future changes against. This information will be used to monitor the system for evidence of change via repeated measurements.

One important factor that must be considered is response time; while soil and geologic features significantly influence the aquatic and terrestrial biological systems, their response to air quality change is likely to be slow and difficult to measure in a time span of a few years.

List of Measures

The assumed sensitivity of high elevation systems is partially due to the expectation that much of the area may be bare rock, the geologic material is little weathered or perhaps resistant to weathering, and the soils are coarse and shallow, providing little buffer capacity. A reconnaissance survey of the geology is necessary to focus the limited resources for sampling on sites that are most likely to be susceptible to change. The soil physical and chemical properties recommended for measurement here should not be considered limiting. Other measures will be appropriate when the particular area or air source suggests them, but those included in table 8 will be adequate and reasonable in cost for most areas. If advanced analytical techniques for soil extracts are used, the content of additional metals, for example, might be available at little or no extra cost.

Useful measurements such as bulk density and permeability should be taken where soils contain few stones and allow the extraction of intact volumes with coring devices. Such measurements may be prohibited by equipment needs or excessive time requirements in most alpine areas. While

Table 8.—Measurements for characterizing soils and geology.

Attributes	Methods	Reference no. ³
Soil description Horizons, depth, field pH, texture, structure, color, consistence	Pit at plot edge and extent checked by borings	1
Mineralogy sand, silt clay	(Mineral soil horizons) Microscopic examination X-ray diffraction	2,2a
Laboratory analyses		
carbon	Combustion to CO ₂	3
LOI (ash)	Wt. after combustion @ 550 C	3
pH	1:1 H ₂ O and 1.1N KCl	4
exchangeable ions	1N NH ₄ Ac extract.	5
Ca	Atomic absorption	
Mg	Atomic absorption	
K	Atomic absorption	
Al	Atomic absorption	
Na	Atomic absorption	
Cation exchange capacity	Saturation with Ba repl. with Mg	6
Exchangeable acidity or titratable acidity	BaCl-triethanolamine extract.	7,7a
Percent base saturation	Calculated from measures above	
Extractable SO ₄	Water and phosphate extract. ion chromatography	8
Total N in O horizon	Micro-Kjeldahl	9
Total S in O horizon	Leco combustion to SO ₂	10
Sulfate retained	Equilibrium with sulfate at 2 and 20 mg/l, ion chromatography	11
Metal content	HCl extractable	12
Pb	Atomic absorption, flameless	
Cd	Atomic absorption, flameless	
Zn	Atomic absorption, flameless	
Ni	Atomic absorption, flameless	
Cu	Atomic absorption, flameless	
Inorganic carbonates ¹	CO ₂ release, HCl treatment	13
Intact soil cores ²		
bulk density	volume and mass	14
pore space	calculated from b.d.	14
permeability	tempe cell	14a

¹The test for amount of carbonates in the soil material can be deleted if soil pH in water is neutral or acid.

²Should be taken where soil is relatively stone-free and intact cores can be obtained with reasonable effort with simple cans or coring device.

³References identified in table 10.

these additional physical measurements are useful in characterization, they are not of the highest priority since they are not likely to be sensitive indicators of atmospheric changes. Bulk density concentrations in soil are to be converted to mass-per-area basis.

Table 8 lists the measures to be used in both the initial characterization and in the periodic sampling. The soil description, mineralogy, particle size analysis, and reconnaissance geologic survey would not be repeated. Table 9 lists the detection levels and laboratory precision of the measurements.

Table 9.—Proposed detection limits and laboratory analytical precision goals.

Attributes	Units	Detection limits	Precision goals
Nitrogen	g/kg	1.0	5%
Carbon	g/kg	1.0	5%
Loss on ignition	g/kg	1.0	5%
pH	pH units	---	±0.1
Exch. calcium	cmole/kg	0.02	5%
Exch. magnesium	cmole/kg	0.02	5%
Exch. potassium	cmole/kg	0.02	5%
Exch. aluminum	cmole/kg	0.02	5%
Exch. sodium	cmole/kg	0.02	5%
Cation exch. cap.	cmole(+)/kg	0.1	5%
Exch. acidity	cmole/kg	0.1	5%
Sulfate	mg/kg	0.5	5%
Sulfur	mg/kg	0.5	5%
Lead	mg/kg	0.1	5%
Cadmium	mg/kg	0.1	5%
Zinc	mg/kg	0.1	5%
Nickel	mg/kg	0.1	5%
Copper	mg/kg	0.1	5%
Other metals	mg/kg	0.1	5%
Bulk density	g/cm ²	0.1	5%
Pore space	ml/ml	0.01	5%
Permeability	cm/hr	0.1	5%
Carbonate	g/kg	1.0	5%

Requirements

Initial characterization of the geology and soils, including writing descriptions, requires the services of two highly trained individuals--a soil scientist and a geologist--both with field experience. Subsequent field sampling of soils can be accomplished by technicians. Approximately one day per site is required for the geologist and soil scientist, assuming the goal is to characterize an area of less than 3 km². Subsequent periodic sampling can be accomplished in one day per site.

Field equipment to be transported into the area is listed below. All equipment needed for the soil and geologic characterization and sampling is transportable on one pack animal.

Soil auger
Sampling tube
Spade
Knife
Topographic maps and aerial photographs
Field pH kit
Soil color book
Notebook
Measuring tape
Polypropylene sample bottles (1 L)
Cloth and plastic bags
Compass
Abney level

Table 10.—References for analytical techniques.

Reference no.	Citation
1	Soil Survey Staff. 1981. Soil Survey Manual. USDA--SCS, Agriculture Handbook No. 430, U.S. Government Printing Office, Washington, DC. Chapter 4.
2	Robarge, W.P. and I. Fernandez. 1986. Laboratory Analytical Methods Manual (draft). U.S. EPA, Washington, DC. pp. 102-105.
2a	Klute, A. 1986. Methods of Soil Analysis, Part 1. 2nd Edition, ASA Monograph No. 9, American Soc. Agronomy, Madison, WI. pp. 185-186, 336-356.
3	Page, A.L., R.H. Miller, and D.R. Keeney. 1982. Methods of Soil Analysis, Part 2. ASA Monograph No. 9 (2nd ed.), American Soc. Agronomy, Madison, WI. pp. 539-552. (Also see Robarge and Fernandez, pp. 179-180.)
4	Page, A.L., R.H. Miller, and D.R. Keeney. 1982. pp. 208-209. Robarge, W.P. and I. Fernandez. 1986. pp. 130-134.
5	Robarge, W.P. and I. Fernandez. 1986. pp. 130-140. Page, A.L., R.H. Miller, and D.R. Keeney. 1982. pp. 159-164.
6	Page, A.L., R.H. Miller, and D.R. Keeney. 1982. pp. 149-157.
7	Page, A.L., R.H. Miller, and D.R. Keeney. 1982. pp. 159-164.
7a	Robarge, W.P. and I. Fernandez. 1986. pp. 141-148.
8	Robarge, W.P. and I. Fernandez. 1986. pp. 159-164. Johnson, D.W. and G.S. Henderson. 1979. Sulfate adsorption and sulfur fractions in a highly weathered soil under a mixed deciduous forest. Soil Sci. 128:34-40.
9	Page, A.L., R.H. Miller, and D.R. Keeney. 1982. pp. 595-622.
10	Page, A.L., R.H. Miller, and D.R. Keeney. 1982. pp. 501-534. Robarge, W.P. and I. Fernandez. 1986. pp. 130-134.
11	Johnson, D.W. and G.S. Henderson. 1979. Robarge, W.P. and I. Fernandez. 1986. Blume, L.J. 1985. Statement of Work, National Acid Deposition Soil Survey. Chemical and Physical Characteristics of Soils. IFB No WA 85-566 EMSL, U.S. EPA, Las Vegas, NV.
12	Robarge, W.P. and I. Fernandez. 1986. pp. 149-153. Page, A.L., R.H. Miller, and D.R. Keeney. 1982. pp. 323-334, 347-362.
13	Page, A.L., R.H. Miller, and D.R. Keeney. 1982. pp. 188-191.
14	Klute, A. 1986. pp. 363-667.
14a	Klute, A. 1986. pp. 694-700.

Soil coring device with removable rings
Frame, 20 cm X 20 cm
Camera
Ground cloth
Rock hammer

Field Procedure

Site Selection Process and Geologic Characterization

The site selection process will be the responsibility of the land manager, and quite specific for each region. We suggest a hierarchical approach working from very large land areas, such as the entire wilderness area, down to selecting the landscape units (small watersheds, for example) that will be

characterized and sampled. All of the available information from numerous disciplines should be integrated in the landscape unit selection process. Information on geology, soils, aquatics, vegetation, and general knowledge of the area, including public concerns and proximity to known or potential contamination sources, will be useful.

After landscape units are selected, plots, lakes, and streams are selected for more intensive characterization and long-term monitoring. Each watershed or landscape unit selected is mapped for bedrock and surficial geology on a reconnaissance scale. The soils are mapped at the same scale and differentiated at family or subgroup level, or mapped by soil associations if recognized soil series are available. Since these mapping procedures are somewhat subjective and require a trained scientist following established procedures common to the discipline, they are not included here.

Sampling Strategy

Conceptually, a few carefully chosen plots can be considered representative of sensitive areas, even though they may not be truly representative of the entire area of concern. A few plots thoroughly characterized for soil and vegetative properties can be monitored for change more easily and result in higher probability of detecting adverse impact than a sampling scheme directed at whole watersheds or whole wilderness areas.

Selection of plots begins with a map survey (using aerial photographs) and the selection of specific landscape units thought to be the most sensitive. The sampling plots themselves should be representative of major soil-geologic-vegetative types within the landscape unit chosen. Whenever possible, the sample plots should be coordinated with those for aquatics and vegetation. In addition, the choice of location should also consider proximity to pollution sources, public concerns, and area coverage.

Location of plots.--Due to size, diversity, and spatial variability, permanent plots will be established in selected geology-soil-vegetation associations within major watersheds surrounding lakes and/or streams that are being sampled. This strategy will provide the opportunity for more precise characterization of small, representative segments of the area under study, rather than attempting to characterize current conditions throughout the area. Because of the lack of any prior classification scheme in which "associations" in these regions are recognized, on-the-spot classifications and descriptions will usually be necessary.

Size of plots.--Alpine mosaics, whether recognized as patches or as changes along gradients, are usually finer grained than even a tenth of a hectare. Therefore, plots will by necessity often include more than one vegetation "type" in order to provide adequate size for repeated sampling without destruction of the site. Although some flexibility in size is necessary to accommodate differences in fineness

and complexity of the soils-geologic-vegetative types, we recommend a target size of 1000 m².

Sample Location, Number, and Frequency

The reconnaissance geologic survey maps and aerial photographs will be used on-site to select plots for detailed characterization. These plots will be limited in number, depending on the size and complexity of the watershed or other geologic unit selected. The plots should be the same as those used in the vegetation studies. Plots should be permanently marked at four corners with flush markers located on photographs by reference to prominent landmarks.

For the initial characterization, a single soil pit is dug at the edge of the plot for detailed descriptions, and approximately 1-liter samples are collected, horizon by horizon, to a depth of 1.5 meters or to a limiting layer. Borings (which minimize disturbance) are taken around the periphery of the plot to ensure that the pit is representative of most of the soil over the plot.

Because one goal is to measure temporal trends, the emphasis is on surface soil samples. Deep samples are needed for complete characterization of the site. Within each permanent plot, 12 samples each of the 0 horizon(s), if present, and top 2 cm of surface mineral horizon are taken at each sample interval.

Samples taken to detect changes should be collected on a 5- to 10-year cycle. More frequent sampling is unlikely to show changes, even in severely contaminated areas.

Sample Collection Procedure

Sample pH should be determined immediately in the field by the dye technique (table 8). Organic horizons can be placed directly into bottles or plastic bags after separation of the mineral soil. The 0 horizon samples should be collected from within a known surface area by cutting around the inside of a 20 cm X 20 cm frame. Moist mineral soil samples gently crushed and passed through a 2 mm stainless steel screen should be placed in 1 L polypropylene bottles for transport. Bottles should be permanently numbered. A record of bottle number, sample location, depth, date, and remarks should be kept and as much information as possible also recorded on the bottles. An estimate of percentage of material above 2 mm (that screened out) should be recorded. Samples of the coarse material should be taken in cloth bags for mineralogical analysis. Initial samples taken from the pit should include undisturbed core samples, representative of each horizon, for bulk density, pore space, and permeability tests.

Field Storage and Handling

Soil samples for pH, extractable sulfate, and nitrogen should be maintained as moist and cool as possible until they reach the laboratory, where the sample can be split. An aliquot for the above analyses is stored at 4°C and the remainder is air-dried for physical and chemical

analyses. Air-dried samples can be stored indefinitely at room temperature.

Hydrologic Sampling

In remote areas, the sampling of springs and seeps offers the best approach to sampling soil water. Sites are permanently marked for sequential sampling, and subjected to analyses prescribed for lakes and streams. Alternatively, tube lysimeters could be installed for periodic sampling if groundwater measurements are essential, but the procedures are not described here.

Laboratory Analysis

Only the initial samples will be subjected to

bulk density, permeability, mineralogical, and textural classification.

The characterization samples and the surface horizons collected repeatedly should be analyzed for the chemical properties shown in table 8. The methods to be used are found in the references cited in table 8 and listed in table 10.

Support Needs

Because the soil sampling should support the vegetation analyses and the aquatic characterization, their locations must be coordinated.

Aquatic Chemistry

Purpose

The objective of this section is to provide guidance for determining current chemical characteristics of surface waters in alpine and subalpine wilderness areas. The proposed guidelines are essentially limited to sample acquisition, stabilization, and analysis.

Development of a detailed sampling program for application in all potential study areas is not feasible. Area-specific information, including the expected nature of potential impacts, and the spatial and temporal variation in measurable response parameters, must be considered. Although design issues cannot be pre-specified, in general a two-stage strategy is recommended for determining current chemical characteristics of surface waters. Stage I would determine the presence and spatial distribution of sensitive surface water systems. The level of effort required at Stage I will depend on the amount of existing information. Stage II would then involve the selection of sensitive system(s) for more intensive study and longer-term monitoring. If information on historical rates of deposition is required, sediment coring could be a component of Stage II, and would require additional protocols.

The following protocol is proposed as a practical approach to obtaining an initial characterization of current chemistry of lakes and streams in remote high-elevation wilderness areas. In conjunction with a sampling design appropriate to local conditions, these attributes and this sampling and analysis methodology should meet a Stage I objective of establishing the range and distribution of chemically differing aquatic systems. A sufficiently reliable basis would be provided for establishing classes of aquatic systems according to sensitivity of response types. Depending upon further

definition of objectives, a more rigorous sampling and analysis protocol could be implemented for the Stage II sampling program to identify temporal variation and trends.

Land managers may view the methods of investigation described within this protocol as general guidance rather than detailed requirements. Methods actually employed would depend upon the potential AQRV impacts, the resources available for the task of characterization, and the specific management objectives.

List of Measures

Major Ions in Water (including Al)

Table 11 provides a general list of measurements important for characterizing surface water composition. The list includes the major mineral species commonly present in low ionic strength surface waters, and the basic parameters associated with nutrient status and biological productivity. The list of measurements may be considered optimal, though not all-inclusive, depending upon case-specific conditions. Some constituents, including aluminum fractions, dissolved organic carbon, fluoride, and ammonium, are commonly present at very low concentrations. After confirmation of low concentrations, these measurements could be deleted, or obtained on a less frequent basis than other constituents. Dissolved oxygen and transparency measurements would only be obtained when mid-lake sampling is conducted.

Table 11 also lists the recommended methods of sample analysis. Accuracy and precision goals are listed in table 12. Sample container and preservation requirements are listed in table 13. Sample holding times are listed in table 14. Specific analytical procedures are provided by reference to the National Surface Water Survey

Table 11.—Measurements required for characterizing water quality conditions.

Attributes	Methods
Alkalinity	Gran's method
Aluminum (labile and total)	Atomic absorption spectrophotometry (graphite furnace)
Ammonium	Standard indophenol blue technique
Calcium	Atomic absorption spectrophotometry or ICP
Chloride	Ion chromatography
Chlorophyll a ¹	Methanol extraction/fluorescence
Dissolved organic carbon	Infrared spectrophotometry
Fluoride	Ion-selective electrode and meter
Magnesium	Atomic absorption spectrophotometry or ICP
Nitrate	Ion chromatography
pH	pH electrode with expanded-range pH meter (closed system)
Phosphate	Standard molybdenum blue technique
Potassium	Atomic absorption spectrophotometry
Silica	Standard molybdenum blue technique or ICP
Sodium	Atomic absorption spectrophotometry
Sulfate	Ion chromatography
Conductance	Conductivity cell and meter
Dissolved oxygen	Dissolved-oxygen meter
Transparency	Secchi disk

¹Chlorophyll a determinations are included to support the aquatic biology protocol in the following section.

(NSWS), a regional-scale survey of stream and lake chemistry conducted by the U.S. EPA. The NSWS provides the most credible and well-documented protocol for determination of chemistry in natural, low ionic strength waters. This project includes a Western Lake Survey conducted in cooperation with the Forest Service. The results of this work should provide an improved perspective on sampling and analysis methods as well as on the degree of precision and accuracy attainable.

Of specific interest is the comparative study of pH measurements, including the development and use of a closed system pH determination. Preliminary results favor this method based on precision and accuracy levels. Inclusion of this method in the proposed protocol would eliminate the need for in situ pH determinations, which would greatly expedite the sample collection process. The NSWS is ongoing, with important methodological findings still emerging. The methods proposed may not fully reflect the current information status; the proposed protocol should be considered tentative and subject to modification as results of the NSWS and other current studies supporting methods assessment become available.

The recommendation for use of NSWS methods should be viewed as guidance rather than prescribed requirements. Any alternate methods employed should attain equivalent levels of

Table 12.—Proposed detection limits and analytical precision and accuracy.

Attributes	Units	Detection limits	Relative standard deviation ¹	Accuracy maximum bias
Alkalinity	ueq/l	5	10%	10%
Aluminum, total	mg/l	0.005	20%	20%
Aluminum, extractable	mg/l	0.005	20%	20%
Ammonium	mg/l	0.01	5%	10%
Calcium	mg/l	0.01	5%	10%
Chloride	mg/l	0.01	5%	10%
Chlorophyll a ²	ug/l	0.02	5%	10%
Dissolved organic carbon	mg/l	0.1	10%	10%
Dissolved oxygen	mg/l	-	5%	5%
Fluoride	mg/l	0.005	5%	10%
Magnesium	mg/l	0.01	5%	10%
Nitrate	mg/l	0.005	10%	10%
pH				
Field	pH units	-	-	-
Lab	pH units	-	-	±0.1 pH
Phosphate, total dissolved	mg/l	0.002	20%	20%
Potassium	mg/l	0.01	5%	10%
Silica	mg/l	0.05	5%	10%
Sodium	mg/l	0.01	5%	10%
Sulfate	mg/l	0.05	5%	10%
Conductance at 25° C	uS/cm	-	1%	5%

¹1RSD at concentrations 10X above detection limits.

²Chlorophyll a determinations are included to support the aquatic biology protocol in the following section.

precision and accuracy, or be otherwise justified. Detailed documentation of any methods used should be considered a necessity.

Trace Metals in Sediments

Trace metals in sediments can provide historical deposition records. Studies in Rocky Mountain National Park and in the Wind River Range indicate a history of atmospheric input of some heavy metals (most notably Pb) over a +100-year period. Collecting this record is a viable research goal to determine the history of the input of atmospheric pollutants that are preserved (not necessarily in proportion to atmospheric flux) in lake sediment or peat. (There are probably few ombrotrophic bogs suitable for such studies.) Briefly, we suggest the following in conjunction with Stage II sampling if information is needed on historical deposition rates.

1. Coring of lake sediment from selected lakes.

2. Abbreviated analysis of sediments to establish approximate chronology and compare pre-1800 to modern chemical-biological characteristics.

3. Sample intervals: 1-2, 5-6, 10-11, 15-16, 20-21, 25-26, 30-31, 35-36, 40-41 cm.

4. Chemical parameters: ²¹⁰Pb activity,

Table 13.—Recommended sampling aliquots, containers, and preservation.

Container and preservation			
1 (1000 ml) LDPE bottle	2 (125 ml) LDPE bottle	3 sealed 60-ml syringe	4 sealed 60-ml syringe
Kept cold in dark	pH < 2 with H ₂ SO ₄	Kept cold in dark	Kept cold in dark
----- Attributes -----			
Cl ⁻	DOC	pH ³	Al ¹
F ⁻	NH ₄ ⁺		
SO ₄ ²⁻			
NO ₃ ⁻			
SiO ₂			
Ca ²⁺			
Mg ²⁺			
K ⁺			
Na ⁺			
Total P			
Total Al			
Al ²			
Alkalinity			
Spec. conductance			
pH ²			

NOTE: As stated in text, concentrations of DOC, Al, and NH₄ are usually low and may not require routine analysis. In that case, only two aliquots, (1) and (3), would be collected.

pH² = laboratory pH, open system measurement, obtained at lab temperature with an open system.

pH³ = closed system pH.

Al¹ = laboratory extraction of closed system sample for organic and inorganic fractions.

Al² = total Al.

Chlorophyll a: Field extracts are obtained according to Holm-Hansen and Riemann (1978).

H₂O and organic content, major metals (Cd, Mg, K, Na, Al, Fe, Mn), trace metals (Pb, Zn, Cd, Cu, B), polycyclic aromatic hydrocarbons, charcoal, and soot.

5. Biological parameters: diatoms, chrysophytes, and pollen.

It will also be possible to evaluate the flux of anthropogenic material (atmospheric pollutants) to the sediments.

Coring of lake sediment is difficult, and is even more difficult given the constraints imposed in wilderness areas. If sediment coring is deemed necessary, a well-developed protocol will be necessary.

Trace Metals in Water

We recommend that only labile and total aluminum be determined in the surveys because aluminum is biologically important, it is very sensitive to changes in pH, and natural levels can be measured with fair precision and accuracy.

We do not recommend that other metals be measured because none have been identified as having effects on biotic systems at natural levels, natural variability is high and therefore trends will be difficult to discern, and trace metals are difficult (and expensive) to collect and analyze at natural levels.

Table 14.—Analysis time frame.

On site	Same day	One week	Four weeks
pH ¹	pH ²	pH ³	SO ₄ ²⁻
DO		Al ¹	NO ₃ ^{-*}
		DOC	SiO ₂
		NO ₃	Al ²
		Specific conductance	NH ₄ ⁺
			Ca ²⁺
			Mg ²⁺
			Na ⁺
			K ⁺
			Cl ⁻
			F ⁻
			Total PO ₄ ³⁻
			Alkalinity

pH Options: 1. In situ pH, open system measurement obtained at field temperature.

2. Laboratory pH, open system measurement, obtained at lab temperature.

3. Closed system pH.

Al¹ Laboratory extraction of closed system sample for organic and inorganic fractions.

Al² Total Al.

NO₃* The NWS holding time is 1 week, but some evidence indicates stability for 2-4 weeks if maintained at 4°C in the dark.

Chlorophyll a: Maximum of three weeks - see Holm-Hansen and Riemann (1978).

Requirements

Manpower

The level of effort required to collect the recommended samples has two components: 1) traveling to the sampling site, and 2) sampling the water and sediment. The amount of time required to get to the sampling sites will be site-specific and cannot be prescribed except to say that enough travel time should be allocated so that field operators can perform careful work at the sampling site.

The amount of time required to take the water samples is approximately 0.5 day, although individual sites may require longer. To take sediment cores, an additional 0.5 - 1 day is necessary.

Equipment

Backpacks

Sampling containers for each location: 1 1000-ml LDPE (low density polyethylene) bottle, 1 125-ml LDPE bottle, and 2 60-ml syringes

pH and conductivity meters

Ice and coolers for samples

Raft when taking mid-lake samples

Van Dorn bottle, dissolved oxygen meter, and Secchi disk when taking mid-lake samples

Field Procedures

Sampling Strategy

Stage I in a two-stage sampling strategy would be conducted to determine the distribution of sensitive lake and stream systems. The level of effort required at this stage will depend upon the value of existing data. Existing data would be adequate if determined sufficient to identify the most sensitive landscape units and place the watersheds in sensitivity classes. Synoptic survey data should be obtained that reflect the spatial scale and distribution of response controlling landscapes. Records of existing surface water chemistry, as well as maps of surficial materials (soils and geology) and vegetation, should be employed in identifying landscape units and in determining additional data collection needs. Even where surface waters can be lumped into general sensitivity classifications, a more detailed survey focused on individual classes may be useful for identifying the most sensitive class members.

Stage II would require selection of the most sensitive class, or classes, of lakes and streams for monitoring and more intensive study. Ideally, one small, well-defined watershed would provide an excellent study area for measurements of aquatic chemistry and biology, and also vegetation and soils. These measurements are easier to perform, interpret, and subsequently monitor when they are made within the same known watershed.

Location of Sampling Sites at Lakes and Streams

If mid-lake samples are to be taken, lakes should be sampled 1.5 meters below their surface in the middle of the lake. Samples of the outlet and a major inlet also should be sampled at a location with appreciable water flow (i.e., no stagnant pools).

Streams should be sampled mid-stream in areas of appreciable flow.

Number of Water Samples and Frequency of Sampling

Two to four aliquots should be taken at each site, depending upon the suite of analyses. Each aliquot has its own preservation and treatment protocol (table 13). This sampling protocol generally is adopted from the NSWS. Our protocol differs from the NSWS protocol in that it does not recommend filtering (because of contamination problems and the lack of large amounts of suspended particulates in the high elevation surface waters) and sampling treatment is minimized. This recommendation does not preclude filtration warranted by site conditions (e.g., high turbidity) or emphasis on a specific parameter (e.g., concentration of dissolved phosphate).

At least 10 percent of all sampling and analysis should be done in duplicate to provide an indication of the uncertainty associated with the sampling and analysis procedures. Additional quality assurance protocols should be used as described in the quality assurance plans developed for the NSWS (see Drouse et al. 1986). At a minimum, quality assurance should

include analysis of sampling replicates, blanks, and NBS traceable reference standards.

Sample frequency should include 3-4 samples per year taken between early spring and early autumn. The exact date of the first sample will depend upon field conditions.

Water Sample Collection Procedures

The lake and stream water sampling procedures of the NSWS (1986) should be used. In general, lake and stream samples should be collected with LDPE sampling containers that have been acid-washed and copiously rinsed with deionized water. At the sampling site, the bottles and the caps should be rinsed 3 times with the lake or stream water before taking the sample. The syringes should be rinsed three times prior to sample collection. Samples should be placed on ice immediately after collection.

Field Measurements

We recommend that specific conductance measurements be taken each time samples are collected. Dissolved oxygen and transparency would be measured on site when mid-lake sampling is conducted. In situ pH measurement (pH₁ in table 11) can be taken if the closed system measurement (pH³) method is not used. We recommend closed system pH measurement because of the low precision associated with in situ open system measurements. If in situ pH₁ is measured in lieu of the closed system pH³, we recommend that an open system lab measurement (pH⁻) also be made.

Water Sample Storage and Transport

Immediately after collection, the samples should be packed in an insulated container with a refrigerant, and thereafter maintained in the dark at approximately 4°C until analyzed.

Laboratory Sample Analyses

The recommended methods for analysis of water samples are listed in table 11. (Note preceding statement concerning use of alternate methods.) These methods are described by Hillman et al. (1986). The appropriate units of measure are listed in table 12.

Support Needs

No biological measurements are required to support the chemical measurements.

In addition to the physical measurements already mentioned (e.g., transparency), additional physical measurements are water temperature and, in the case of streams, water flow.

Data Analysis

Data analysis that would be required in addition to standard statistical analyses to determine data quality, depend on the objective of the study and how well it is realized in the sampling design and, thus, cannot be prescribed here.

Aquatic Biology

Purpose

The primary objective of monitoring aquatic biota in wilderness areas is to provide information on the status of sensitive biological communities over time. Man-induced change or lack of change can then be inferred from data patterns. This general goal must be considered within the context of limited monitoring resources (constraints of time, money, access to sampling sites) which, for example, may preclude the study of seasonal biological dynamics. Cause-and-effect relationships between anthropogenic disturbances and biological responses also cannot be delineated (except for catastrophic change) in complex ecological systems by monitoring alone. Moreover, the sensitivities of specific aquatic biota to different anthropogenic stresses generally are poorly known in subalpine and alpine regions. Consequently, the monitoring activities described here represent our best approximation of a minimal array of sensitive components that, if monitored with reasonable intensity and frequency, will provide an estimate of the health of aquatic communities in remote wilderness regions.

Although sampling error undoubtedly will be high (i.e., high variance among replicate and time series data), we have little alternative to accepting high error short of simple presence/absence surveys or no monitoring at all. Although present monitoring methods may be crude, it is obvious that the alternatives are undesirable from a resource management perspective.

The biological components that constitute a minimal set for detecting change in alpine and subalpine waters are Chlorophyll a, salmonid fisheries, and macroinvertebrates. Chlorophyll a (tables 11 and 12, Aquatic Chemistry) is the best readily measurable attribute of phytoplankton biomass (primary producers) related to the trophic status of surface waters, which may be stimulated (fertilized) or reduced by atmospheric deposition. Macroinvertebrates and salmonid fish are sensitive to many types of anthropogenic disturbances; are not typically ephemeral in a given lake or stream (although specific life-cycle periods are ephemeral); can be quantitatively monitored by routine field practices; and in the case of fish, are highly valued components of wilderness surface waters.

Monitoring of other aspects of lower trophic levels (such as phytoplankton and zooplankton community structure) presently is not recommended as part of the minimal set for the following reasons:

1. these lower trophic levels have high natural variability, both seasonally and year-to-year;

2. we do not understand the complex of factors that drives the shifts in community

structure or biomass during early stages of anthropogenic disturbance (e.g., lake and stream acidification) especially in low-productivity systems;

3. they have low or unknown sensitivity to change during early stages of anthropogenic disturbance; and

4. archiving of biological samples for future analysis is not likely to be feasible.

However, anthropogenic stress affects a broad variety of aquatic organisms. The wilderness resource manager should consider expanding the minimal monitoring program suggested in this protocol as resources permit. Studies that may be particularly useful include studies of attached algae, macrophytes, zooplankton, and amphibians (particularly salamanders).

As previously noted, these protocols are intended to be general guidelines rather than detailed field manuals or research directives. Although we recognize that alternative monitoring approaches such as remote sensing of the trophic status of wilderness lakes have great potential to increase the accuracy and geographic extent of the monitoring effort, such developmental approaches are not discussed here.

Salmonid Fish

The following protocol is constrained by limitations of access, time, manpower, and transport of equipment inherent in sampling of high-elevation lakes in remote wilderness regions. Such limitations dictate that only a small set of basic data be collected to characterize fish stocks. Further assumptions used to develop this protocol are described in the following paragraphs.

The general objective of this protocol is to correlate independent fishery variables with changes in surface water quality. However, quantitative assessment of fishery stocks in remote lakes for long-term trend analysis is not well developed. Most monitoring of high-elevation fisheries has been biased toward general management goals that do not require a high degree of accuracy or precision of technique. For example, the efficiency of sampling effort using specific gear is a function of fish species, standing stock, seasonal behavior, habitat, and morphometric features of lakes, and is not quantified for high-elevation salmonid fisheries. Little guidance on the quantification of alpine salmonid fish stocks can be derived from existing data. Consequently, collection of unbiased fishery data in wilderness lakes is unlikely (Thornton et al. 1986).

Because the availability of sampling gear at each lake will be limited, sampling for target fish species will be emphasized. This may preclude complete characterization of the fish community in some lakes. However, many alpine and subalpine lakes did not historically contain

fish, and existing fish populations have been established by stocking.

Therefore, many high-altitude fisheries contain only one or two species of introduced salmonids. For example, only a few cutthroat populations were found historically in the high-elevation lakes of the Wind River Mountains in Wyoming. Other fish species associated with oligotrophic conditions are not commonly found. For example, sculpins, suckers, and dace are not found in high-elevation lakes in Wyoming due to high gradient streams, although sculpins are occasionally found in mid-elevation lakes. Speckled dace and long-nose suckers are found in some alpine lakes in Colorado but their occurrence is not common; both of these species have probably been introduced.

The lakes selected for long-term monitoring should, if possible, also be used for chemical monitoring (see Aquatic Chemistry section). However, monitored lakes must be capable of sustaining fisheries over periods of many years (e.g., probability of winter kill must be low) and the lakes must not exhibit a high degree of heterogeneity of fish habitats (e.g., selected lakes should be relatively circular and not contain coves) which tend to develop sub-populations of fish. Lake morphometry should be relatively uniform, conducive to random dispersal of active fish populations. Harvest by angling should be insignificant compared to natural sources of mortality, and be relatively constant year to year. The potential for over-harvesting by fishermen must be considered during lake selection.

Ideally, lake fisheries that are monitored should be sustained by natural reproduction because early life stages of salmonids are very sensitive to changes in water quality. This may be an impractical constraint, however, because many lake fisheries in alpine wilderness regions are maintained by periodic stocking. In addition, the availability of spawning habitat has been found to be positively correlated with population strength and size of individual fish in wilderness lakes (Hudelson et al. 1980).

Salmonid fisheries are assumed to be of primary interest. Such fisheries are to be sampled once during a sampling year over a 2-3 day period using equipment that can be transported to the site. The field crew should consist of 2-3 individuals using an inflatable raft. A requirement for non-destructive sampling in wilderness lakes will be adhered to as much as possible, but complete elimination of sampling mortality is difficult.

Experience has shown that absolute measures of fish stocks are difficult and time-consuming in the alpine (e.g., mark-recapture techniques require at least one week of sampling). Thus, the specific objectives here are to quantify relative indices of fishery status. These include (beyond presence of a specific fishery) the following:

1. catch per unit effort (CPUE),
2. population age structure,
3. condition factors,
4. growth and mortality rates, and
5. absence of year classes or weak year classes.

Field Sampling

Sampling design.--Collection of representative, random samples of individuals from a fish stock optimally should be based on a stratified random sampling design where strata represent different habitat types. In alpine lakes that have restricted sampling area (due to steep morphometry, boulder fields, or other morphometric features), site-specific judgement on net placement may be based on experience with collecting mobile salmonids if experience dictates that a representative sample of fish from the total stock will be collected.

Sampling frequency.--It is generally recommended that the frequency of fish sampling be related to the potential rate of change of surface water chemistry (Lambou et al. 1985). For intensively monitored lakes where close observation of fishery status is desired in the event that such lakes undergo rapid change (e.g., dilute headwater lakes), fish should be sampled at 1- to 2-year intervals. For lakes not expected to exhibit rapid chemical change (e.g., larger or less dilute subalpine lakes), fish should be sampled at 3- to 4-year intervals (Lambou et al. 1985). Fish should be sampled once during mid to late summer so that young-of-year may be observed. This time will vary from late July to late August, depending upon whether fish spawn in fall or spring.

Sampling intensity.--Sampling intensity should involve both minimal sampling effort and minimal sample sizes. Minimal sampling effort should be expended at each monitored lake according to the recommended number of net sets for lakes of given sizes (see Net Placement). Minimal sample size should be collected according to the following protocols.

For each monitored species, 100-150 fish should be collected, with 150 being preferred. Some field experience suggests, however, that as few as 30 captured individuals may be adequate to characterize fisheries with limited stock size (Remick 1984). Other recommendations include sampling at least 10 fish per 2 cm size length over the size range of maximum accuracy for individual fish statistics (see discussion below). Lambou et al. (1985) recommend that at least 60 fish evenly distributed across size classes be measured for developing fishery statistics (see also Thornton et al. 1986).

It should also be noted that stressed fish populations contain the fewest individuals and require the greatest effort to achieve population estimates of known variance.

Field Procedures

Sampling gear.--Because collecting unbiased fishery data is difficult, more than one type of sampling gear should be used. However, experience has shown that monofilament gill nets are effective in collecting most fish species found in remote Rocky Mountain lakes (e.g., Hudelson et al. 1980) and are easily transported. Trap nets are presently being designed that are more portable than previously available (e.g., modified Alaska trap net; ALSC 1985). Such nets may become useful in the future to supplement gill netting, although portable trap nets did not prove effective for surveying

fish stocks in small Maine lakes (Haines et al. 1985).

Swedish gill nets (standard 150 ft length, 6 ft depth with 5 panels of 1/2, 3/4, 1, 1 1/2 inch bar mesh) should be used because they are especially effective in capturing mobile salmonid species. These nets are capable of capturing fish as small as 7-8 cm total length. Thus, the gill netting should be effective on age I fish and older, but should not catch young-of-year.

Net placement.--Analysis of trends in fishery status based upon results of gill netting will only be as reliable as the reproducibility of sampling technique for each monitored lake. Location of nets, orientation along the bottom in relation to shoreline, time of placement and collection, and season of placement must be standardized for each lake. Because lake sampling programs will be site specific, standardization must be within a given lake and not necessarily between lakes.

Fish captured by nets operated in a similar manner and time each sampling year should provide reasonably comparable estimates of population characteristics (Hubert 1983). Close adherence to standard collection procedures for each lake will minimize total variance in catch statistics due to unknown or uncontrollable biotic and abiotic factors.

Each lake has a unique morphometry, and net placement must be carefully considered according to lake characteristics and target species. Generally, gill nets set along the bottom in shallow waters not exceeding 5-7 m depth will capture a representative sample of the total fish stock if crepuscular activity periods are sampled. Salmonids in alpine lakes in the Rocky Mountain region are typically found in relatively shallow waters, and in general are closely associated with the benthos as the primary food resource (e.g., golden trout are found in close proximity to sediment). Nets should be placed perpendicular to the shoreline in shallow water or at 45° angles in deep water, with the small mesh nearest shoreline. If the initial sampling effort yields few or no fish, the sampling stations should be moved and the sampling effort repeated.

A rough guideline for number of nets to use is as follows:

<u>Lake size</u>	<u>Number of 150 ft. Swedish gill nets required</u>
Less than 10 acres	1
10-25 acres	2
25-50 acres	3
50-100 acres	4
Each additional 100 acres	add 1 net

Three gill nets set in different habitat may be the maximum number effectively operated by a field crew of 2-3 persons.

Sampling mortality should be minimized in wilderness lakes, especially in those with relatively small fish populations. Thus, gill nets should be deployed by midday in

high-elevation lakes where foraging by salmonids is more or less continuous. These nets should be tended every 1 1/2 to 2 hours to minimize capture mortality. The nets should be run until after dusk to bracket one crepuscular activity period. If fish are abundant, and some sampling mortality is acceptable, one net set over night may be useful to sample larger, night-feeding individuals. Overnight sets where the dusk (one hour before sunset) and dawn (one hour after sunrise) activity periods are bracketed generally will capture a representative sample of fish, but such long sets may produce mortalities above 50% in captured fish.

Fish processing.--Fish in unproductive high-elevation lakes generally grow very slowly in the older age classes due to food limitation. Generally, rapid growth occurs in such lakes only to approximately 20-25 cm in total length. Thus, older fish are more difficult to age accurately by scale readings. Obtaining accurate weights in the field on fish smaller than 12-15 cm also is difficult due to variations in water content and from wind effects on weighing devices. Additionally, the more numerous individuals in the younger age classes place large demands on a lake ecosystem to provide habitat and food. Therefore, it is appropriate to obtain weight-length measurements for all fish captured, unless sub-sampling is required due to large numbers of individuals captured. But fish in the 12-25 cm total length range only should be used to determine the population parameters discussed below.

Handling time should be minimized once fish are removed from the net. Fish should be kept in a live-car attached to the side of the raft during handling, and be released as soon after capture and measurement as possible. Handling mortality should be recorded if observed. Procedures for reducing handling mortality have been reviewed by Stickney (1983).

Fish collected should be carefully removed from the gill net (using a small polished hook to minimize damage to fish and technician), identified to species, measured to nearest mm, weighed to nearest gm (by volume displacement for fish less than 50 gm and by spring scale for fish greater than 50 gm), and scale samples taken (on left side just posterior to and below dorsal fin and above the lateral line).

Recording of field data.--Field data recording should be standardized, and include the following:

- lake;
- sampling date;
- gear type;
- net location, shoreline orientation, depth, placement time, and collection intervals;
- species, weight (gm), total length (cm), and location of scale collection site for each individual fish collected;
- observations of parasites, wounds, deformities, or other abnormalities; and
- capture mortality and injury.

Lake temperature at sampling location and other

pertinent chemical condition information such as dissolved oxygen or pH should be recorded on field sheets, if measured.

Additional fish surveys.--A reconnaissance-level, qualitative assessment of reproductive success can be made by looking for juvenile fish in shallow habitat and in shoreline cover. Small hand seines and dip nets may be used to find young-of-year, but capture success may be limited. Small baited hardware cloth minnow traps have not proved effective in capturing young-of-year salmonids (T. Haines, personal communication). Alternatively, trapping of drifting fry in outlet streams during sampling for macroinvertebrate drift may be possible.

Laboratory Procedures

Use of scales to age individuals from wild salmonid populations during the early rapid growth phases of ages I-IV is the most accurate, non-destructive technique available. However, aging by scale analysis is not as accurate for stocked fish due to possible interruption of growth in the period immediately following stocking. Stocking may produce a growth check similar to an annulus. Fall-spawning species such as lake trout produce a better annulus during age 0 in comparison to species that spawn in late spring such as cutthroat and golden trout. The latter sometimes do not get a good scale growth before the first winter, and produce an indistinct first annulus.

Technicians should be carefully trained using scales from the monitored species that are from fish of known age and comparable growth environment. Random recounting of approximately 5% of fish scales by a second trained technician is appropriate as a quality assurance check. An 80-90% comparison of scale readings between two technicians typically is good (Thornton et al. 1986). If possible, fish scales should be aged by the same personnel over the life of the monitoring effort to minimize error.

Supporting Data

As noted above, the fisheries monitored should be in lakes whose water chemistry is also being monitored. Better resolution of ongoing environmental change or stability will result from such integrated studies.

Data Analysis

Catch Per Unit Effort (CPUE).--Catch per unit effort is a relative measure of population strength. Theoretically, it should be linearly proportional to the abundance of fish stock: catch = capture efficiency x fishing effort x fish abundance. However, capture by passive fishing techniques is a function of fish movement. Consequently, CPUE is not dependent fully on stock size (Hubert 1983), and has frequently been found to be non-linear (Bannerot and Austin 1983). Fishery biologists have long recognized variability in CPUE results from problems of gear efficiency due to interacting biotic and abiotic factors that affect fish movement.

Common problems with CPUE studies include spatial correlation among sampling units, inverse

non-linear relationships between capture efficiency and population abundance, and skewed frequency distributions for CPUE with zero catch being most frequently recorded. (See review in Thornton et al. 1986). The high variability among units of sampling effort (catch per net hour or per net night) may result in poor statistical resolution of stock means or patterns of population fluctuations (Bannerot and Austin 1983, Thornton et al. 1986).

CPUE will therefore provide only semi-quantitative estimates of fish abundance.

Transformed catch data and the relative frequency of zero CPUE have been demonstrated to be the best indicators of population abundance. Catch data should be reported as catch per net hour or per net night (means and variances) for each species captured (Bannerot and Austin 1983).

Population age structure.--Evaluation of population age structure depends on obtaining a representative sample of the overall population. As noted above, passive fishing techniques using gill nets tend to produce skewed data, with older and younger fish being less efficiently captured. Additionally, aging of fish by reading of scales is most accurate in the age I-IV classes for alpine salmonid fisheries. Thus, age-frequency data for y-o-y and older age classes generally will be qualitative. Age frequency distribution within the I-IV age classes will be most quantitative.

Captured fish should be aged by scale readings using standard techniques (Lagler 1956, Jerald 1983). As with CPUE, age frequency data may be transformed to achieve independence of variance and mean.

Condition factors.--Weight and length are quantitative attributes of individual fish that can be easily measured in the field. Relationships between weights and lengths indicate the relative abundance of food and relative quality of habitat for growth. Condition factors for each age class I-IV should be calculated. For example,

$$CF = (W \times 10^5) / L^3$$

where: CF is condition factor
W is weight in pounds
L is total length in inches

Condition factors are typically reported in English units. For comparison with existing data from State game and fish departments, it probably is best to continue using English units (Remmick 1984.)

Relative condition factors or analysis of covariance among weight/length data for specific subgroups captured (for example, grouped according to same species, sex, year-class, and physiological condition relative to spawning) also may be used to assess the general growth environment (Anderson and Gutreuter 1983; W. Nelson, Colorado Div. of Fish and Wildlife, personal communication).

Growth and mortality rates.--If sampling has been random among age classes, determination of growth and mortality characteristics will reveal important characteristics of the fish stock for a particular lake. The dependent variables most

commonly related to water and habitat quality include average annual growth increment, instantaneous growth rate, average length of a given age-class, and instantaneous age-class mortality. Again, age classes I-IV should be used to provide the most accurate calculations.

The variable stocking rates of different age-classes in some wilderness lakes will affect accuracy when estimating fish mortality from catch data. Thus, the mathematical structure used to estimate mortality will depend upon the specific conditions related to annual recruitment (Everhardt and Youngs 1981). For those lake fisheries not sustained by natural reproduction, knowledge of stocking rates (species, numbers, sizes, dates) should be obtained from appropriate fishery management groups. Adjustment of catch data by weighting according to stocking records should follow general recommendations in Everhardt and Youngs (1981). If stocked lakes are extensively monitored, marking of each stocked year-class is feasible and should be considered to improve the accuracy of population parameter estimates.

Average annual growth increment between growth intervals of 1-2 cm can be determined by back-calculation techniques using length at age i , determined by scale analysis (Lagler 1956, Whitney and Carlander 1956, Carlander 1981). Fish growth rates also should be calculated using length-weight regression assuming allometric growth: $W = aL^b$, where a and b are growth coefficients.

Instantaneous growth rate is calculated as the difference between natural logarithms of weight for consecutive age groups (Everhardt and Youngs 1981). If annual fish surveys are conducted, instantaneous age-class mortality (Z) may be calculated from the slope of the regression of age versus frequency:

$N_i = N_{i-1} e^{-Z}$ where N_i is number of individuals captured of i th age for a particular year-class.

Missing or weak year classes.--Observations of missing or weak year classes in a fish stock may indicate changing habitat conditions or density-independent mortality, resulting primarily from weather. Missing or weak year classes are common occurrences in wild fish populations; gear inefficiency and poor age determinations preclude accurate estimates of older age class strength. Thus, for a given lake, the occurrence of missing or weak year classes in catch data is neither a definitive characteristic of the fishery, nor necessarily an indicator of anthropogenic change related to atmospheric deposition. However, patterns of similar age-frequency distributions (number and sequence of low frequency year classes) among monitored lakes in the same region may be indicative of regional conditions or change (Thornton et al. 1986).

Detection Goals

Presently, there are no standard references that quantitatively define detection goals for changes in the indices discussed for high-elevation salmonid fisheries. Comparable analyses of fishery data from remote lakes using

stock assessment by gill netting are being conducted by the U.S. Environmental Protection Agency as part of the National Surface Water Survey. Results of these analyses, which are expected in several years, will help define realistic detection goals for some salmonid species with restricted stock sizes and for limited sampling.

It must be stressed that, due to inherent variability in gear efficiency between lakes, fishery statistics cannot be compared between different monitored lakes, but only within a given lake over a sequence of years.

Based upon reasonable age determination of 1- to 4- year-old fish, changes may be detected in relative growth and mortality indices on the order of 20-50% for specific year-classes, but achievement of these goals is uncertain. Estimates of changes in absolute characteristics of an alpine fish stock will be less precise. Changes in the neighborhood of only 2-3x will be considered valid on the basis of reasonable adherence to assumptions of random sampling of fish stock and independence of variances and means. Estimates of age will be particularly troublesome. In general, aging by scale reading produces estimates of higher mortality rates than actually are present due to poor aging of older fish (on the order of 10-20% too high; Jerald 1983). Precision of age determinations should be estimated according to Chang (1982).

Additional protocols for sampling fish may be found in Armour et al. (1983) and from the EPA National Surface Water Survey (Fabrizio et al. 1987, Hagley et al. 1987).

Macroinvertebrates

Aquatic macroinvertebrates are animals without backbones that live in streams and lakes, and are big enough to be seen without a microscope when in advanced stages of development. They have been observed to be sensitive to low pH conditions in lakes and streams (Napier and Hummon 1976; Parsons 1968; Warner 1973; Nichols and Bulow 1973; Tomkiewicz and Dunson 1977; Witters et al. 1984; Havas and Hutchinson 1982; Bell 1971; Hall and Ide 1987; Hall and Likens 1985; Singer 1981, 1984). Tolerances of aquatic invertebrate species vary according to their specific anatomical, behavioral, and physiological adaptations (Hynes 1972). Since some macroinvertebrates are more tolerant to acid conditions than others (Parsons 1968, Warner 1973, Bell 1971, Robak 1974, Eilers et al. 1984, Hall and Likens 1980, Sutcliffe and Carrick 1973), they may be used as a functional part of the warning system established to monitor possible effects of air pollution in high-elevation ecosystems.

The following equipment and procedures are being used by federal and State agencies in western regions of the United States, and may provide a common basis for collection of macroinvertebrate data.

Equipment

Modified Surber net (see fig. 8)

Standard 8" diam. full height 250 micron mesh Tyler sieve

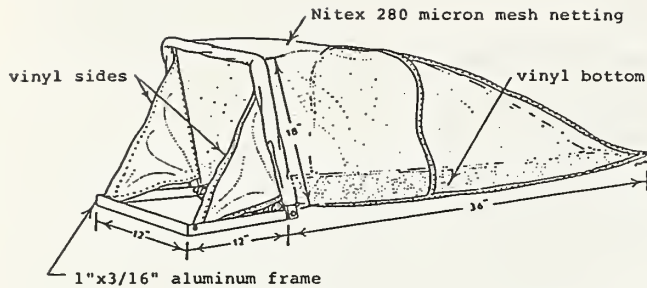


Figure 8.--Modified Surber sampler for use in macroinvertebrate sample collection (from USDA 1985).

8 oz., wide-mouth plastic bottles with strip of masking tape attached for identification data
 Preserving solution: ethyl alcohol plus one cup 10% formalin per gallon of 70% alcohol
 Hip boots
 Saturated salt-water solution
 Two aluminum bread pans
 Waterproof gloves (scuba diving or rubber electrical types recommended)
 Laundry pen (waterproof marker)
 Long-handled 250 micron mesh kick net
 White plastic tray--2.5" x 10" x 12"
 Fine-pointed forceps

Sampling Station and Site Selection

Stations should be established in the inlet and outlet streams of the lake ecosystem to be monitored. In a literature review, Eilers et al. (1984) observed that, with few exceptions, taxa were found in lakes at lower pH values than were taxa in the same order or family in streams. This was mainly because species in streams may experience more short-term pH depression. The sampling station should be in a riffle area having unimbedded rubble substrate (3-12" rocks) if possible. If rubble substrate is not found, whatever substrate is present in the riffle should be sampled. Most of the macroinvertebrate species present will be found in the rubble substrate, which has been called the "breadbasket" of the stream (Bell 1969, Cairns et al. 1971, Hart and Brusven 1976, Pennak 1977).

Number and Frequency of Sampling

Quantifying stream benthic macroinvertebrates is difficult due to the spatial and temporal variation in species abundance (Needham and Usinger, 1956). As a minimum, three random samples should be taken at each station. Ideally, sites should be sampled with as many samples as possible. Following the recommendations of Elliott (1977), enough samples should be taken such that the standard error is equal to or less than 20 percent of the mean. The needed number of samples should be established for each site for each sampling

season. Under ideal conditions with good access, samples should be taken at least monthly. Year-to-year variation in benthic community composition requires that a site should be monitored for several years.

Modified Surber Net Samples

The modified Surber square foot sample net is recommended for use, because it performs better than alternative sampling devices. The 3-ft-long net and 18-in-high upper frame (fig. 8) reduces the backwash problem often experienced with the original Surber net (USDA 1985).

Sampling Procedure

Streams.--The foot-square modified Surber frame is placed over the gravel-rubble substrate in the stream with the net downstream. As the rocks within the frame are scrubbed, the macroinvertebrates are carried into the net by the flowing water. The substrate underlying the gravel-rubble is also stirred to a depth of 3-4 in (7-10 cm), if possible.

After the water drains from the net, the net is inverted into an aluminum pan containing a saturated salt-water solution. As the salt water is poured into a second pan, the organic materials thus floated are caught in a 250-micron sieve. The salt water is then poured back into the first pan, the contents again vigorously stirred, and the floating materials and specimens are poured for a second time into the sieve. The sample may require sieving two, three, or more times. It is imperative that the pan material be inspected carefully so that non-floating benthos are hand picked and collected. Clams, snails, and cased caddisflies will not float and must be hand picked and added to the sample. Large clams will also not float into the net, and should be sampled from within the Surber frame by hand.

The sample in the sieve is then washed from the sieve pan into the sample bottle with an alcohol solution. Enough alcohol should be added to the sample bottle to cover the sample.

Lakes.--Macroinvertebrate sampling within a lake should include qualitative lake-shore samples for sensitive indicator mayfly, stonefly, caddisfly, and amphipod species. These samples can generally be taken with a long-handled kick net used in a sweeping motion through vegetation or over the lake bottom substrate.

Portions of the net contents can be placed in a white tray with a small amount of water in the bottom for detection and removal of invertebrate fauna with forceps. If the net contains plant materials, put more water in the tray and vigorously wash the plants in the tray. The water and its contents are poured into the 250 micron sieve and then transferred to the sample bottle. The sample data on the bottle should include the words "Qualitative Lake Sample".

Identification of Taxa Collected

The samples collected should be sent for identification by qualified persons. Taxa should be keyed to the highest taxon possible: family, genus, or species, depending on the group. Voucher collections should be maintained and identifications should be checked and verified.

Once the identity and number of individuals in each sample are known, a variety of analysis methods are available.

Data Evaluations

The resultant data (numbers of individuals of each taxon per sample) may be analyzed by a number of methods. Analysis may include the use of indicator species, community composition, synthetic "biotic indices," biomass, abundance, species richness, species diversity, and functional group analysis. The aim is to quantify existing conditions and identify and interpret changes in the stream benthic community. No one method will suffice. It is most important that the data be collected properly with adequate sampling and accurate taxonomic determinations. The method of analysis is not as important as the data quality itself.

Helpful guidelines for sampling and data analysis of stream benthos can be found in Platts et al. (1983). Sources of materials, and an extensive taxonomic literature review of insects, can be found in Merritt and Cummins (1978). Pennak (1978) provides a scholarly guide to the identification of fresh-water invertebrates and Hynes' (1972) tome remains a classic introduction to the ecology of streams. A comprehensive review of statistical methods can be found in Elliott (1977) and a review of the use of indices is found in Washington (1984).

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Plants

Purpose

These guidelines have been prepared to assist the Federal Land Manager (FLM) in designing a measurement program capable of determining current, and monitoring future, responses of vegetation to atmospheric pollution. They are general guidelines rather than specific methods. They are flexible, and guide the FLM in the development of a program suitable for a specific permit and wilderness area.

These guidelines are built on the ongoing programs of several regulatory agencies that assess the effects of pollution on native plants (see Bennett 1984, 1985), but they represent a new synthesis and approach to the problem. The guidelines are based on the acceptance of the principle that changes should be detected in "the most sensitive part of the ecosystem." They are presented as the most efficient and parsimonious steps to make decisions involving present or future effects of atmospheric pollutants.

A primary goal is to obtain measurements of plant air quality related values (AQRVs) within a short period (one growing season), which can be used in the permitting process. However, if funding and the management policy of the Class I area under consideration allow, a secondary goal would be to establish subsequent trends and changes via long-term measurements.

Constraints and Philosophy of Approach

Biological AQRVs worthy of measurement are inherently more difficult to identify than abiotic AQRVs. Further, the significance of their measured value as an indicator of air quality is often ambiguous. The following points provide the background for this comment:

1. No finite list equivalent to that of criteria pollutants exists for organisms and communities.
2. Because of the lack of adequate controls and experimental design, any field observation or sampling will lead only to correlations and inference, not to an established cause and effect of a pollutant on a biological AQRV unless chronic levels of pollution are present.
3. There are no known functional attributes that respond only to specific changes in air quality. The majority, if not all, functional attributes also will be affected by several pollutants and by natural environmental factors.

Synergism will occur between the various controlling factors. Further, some symptoms may have more than one cause, including those other than pollution.

4. Species and individuals vary in their response to environmental stress because of genetic or ecotypic variability. Again, interactions can complicate the picture. For example, stresses can be mitigated or amplified by temporal patterns of the plants or by involvement with pathogenic organisms.

5. Even the functional attributes that may be reasonably related to changes in air quality are poorly described and quantified. Furthermore, even if the dose-response experiments have been done, extension to the field is tenuous. An overall ignorance of the norm makes many attributes, especially physiological ones, of little value.

Measurements in these western high-elevation and montane Class I areas present further difficulties because of the following:

1. These areas tend to be large, inaccessible, diverse, and spatially heterogeneous.
2. The air quality history or current status may be poorly known.
3. The effects of air quality on the native plants, communities, or biotic systems are not fully known.

The protocol has two key elements. The first is the decision to deal with the population level of the plant system rather than higher attributes of the ecosystem. The second key element is the flexibility and general nature of these protocols, which do not provide exact sampling and measurement schemes. Plants, rather than vegetation, provide the operational perspective, which focuses on the presence and performance (health) of individual plant species and their populations, rather than on attributes of vegetation, communities, or ecosystems. The scope of measurement is further reduced by the restriction only to known sensitive taxa and their sensitive organismic systems. The complexity of higher-order ecological units such as community and ecosystems and the difficulty of measuring change in these units, provide ample reason for a population perspective to take precedence over a vegetational or total system perspective.

Nonvascular plants such as mosses and lichens

are considered because of their known sensitivity to air pollution and their established usefulness as indicators. Algae, bacteria, and fungi are not included because they would require special methods that would be beyond any realistic budget for the task. The flexibility of the protocols is justified on the basis that unique programs have to be designed by the FLM and contributing experts to meet the unique characteristics of each permit, each area, and each flora.

There are two parts to the protocols: 1) a flow diagram or decision tree with text explaining the step-by-step process for designing a specific program, and 2) some general guidelines for sampling and analysis procedures. Although the decision regarding permit denial or approval is beyond the scope of these protocols, the position of the permitting decision process is shown in the flow diagram.

Protocol Design

The flow diagram in figure 9 shows the data sets required at the start of the design process, and the decisions necessary to design a measurement program. The required data are shown in lettered boxes, and the processes and decisions, here called steps, in numbered boxes.

A number of data sets are required to decide what, when, and where to measure the flora. These may be available in the literature or specific archives pertaining to the Class I land under consideration. If not available, they should be compiled by the FLM. Available information seldom will be adequate, and preparation of this information will be a mandate and prescription for collection. These compilations may require assistance from experts. The data sets required for each Class I area are described in the sequence of the lettered boxes of figure 9. This protocol is demanding of time and effort; there are no short cuts.

Floristic List

A complete list of vascular plants, lichens, and mosses is needed. This list should show for each species a commonness rating (abundant, frequent, rare) and distributional information (habitat, soil preferences, vegetation associations). Fairly good lists of vascular plants are available for many Class I areas. If these are not available, local floras, herbarium collections, and consultation with local systematic botanists can supply fairly complete lists that include estimates of commonness. Available lists of lichens and mosses are rarely available, and their compilation would not be easy without field surveys by specialists. Distributional information seldom may be pre-compiled but can usually be derived from such sources as floras, plant ecology dissertations, and plant community descriptions from similar nearby regions. This list is meant as a guide in the selection of taxa to be studied, and not as a definitive list against which future losses can be detected.

Land Cover Map

A map of land cover units at a scale between 12,000 and 100,000 would be satisfactory. The land cover units should be based primarily on vegetation assemblages. Each vegetation unit should be described by species content and abundance, and may be additionally defined on the basis of other attributes such as geology, soil, and habitat. Maps of species distribution, if available, would be particularly useful, especially for a rare species whose distribution is difficult to interpret from a vegetation map.

Adequate land cover and/or vegetation maps will only be available for a few areas. Forest inventory maps, soil surveys, and geology maps may be more readily available and may provide background data for land cover maps. Most Class I areas will have reasonable aerial photo coverage, and a skilled aerial photo interpreter, with the help of a local plant ecologist, can produce adequate land cover maps overlaid on USGS topographic maps (1:24,000 or 1:63,360). The comprehensive method of Kuchler (1967) is recommended. The description of vegetation in terms of its composition is critical to the proposed protocol. According to the Kuchler method, this information is gathered as the groundtruth of the map is verified and revised.

Relative Sensitivity Tables

A fundamental assumption of monitoring air pollution effects on plants is that not all species are sensitive to a given pollutant. Therefore, candidate test species must be sensitive to a given pollutant. Furthermore, we agree with Cairns (1986) that there will also be no single reliable most sensitive indicator species for specific pollutants. Therefore, several test species must be selected. Lists of relative sensitivity of plants to specific pollutants may be found in the literature (Applied Science Associates 1976, Davis and Wilhour 1976). The EPA Criteria Documents for each pollutant are a useful source of lists. National experts are useful contributors of information at this point. When information is not available for the actual species on the study area, related taxa or growth-forms (which often, but not always, have similar sensitivities to a pollutant) might be considered.

Air Quality Information

This is required to identify the probable pollutants of concern. Sources of these data will be any previous monitoring, the direct monitoring provided as part of the total protocol (Atmospheric Environment Section of this report), and from the permit application itself. The most desirable data set would contain temporal and spatial distribution of pollutants, and also the frequency concentrations of each pollutant over the area. Atmospheric modeling is often the best source of this distributional information. Research is ongoing on species sensitivity.

List of Responsive Attributes

It is necessary to measure only those

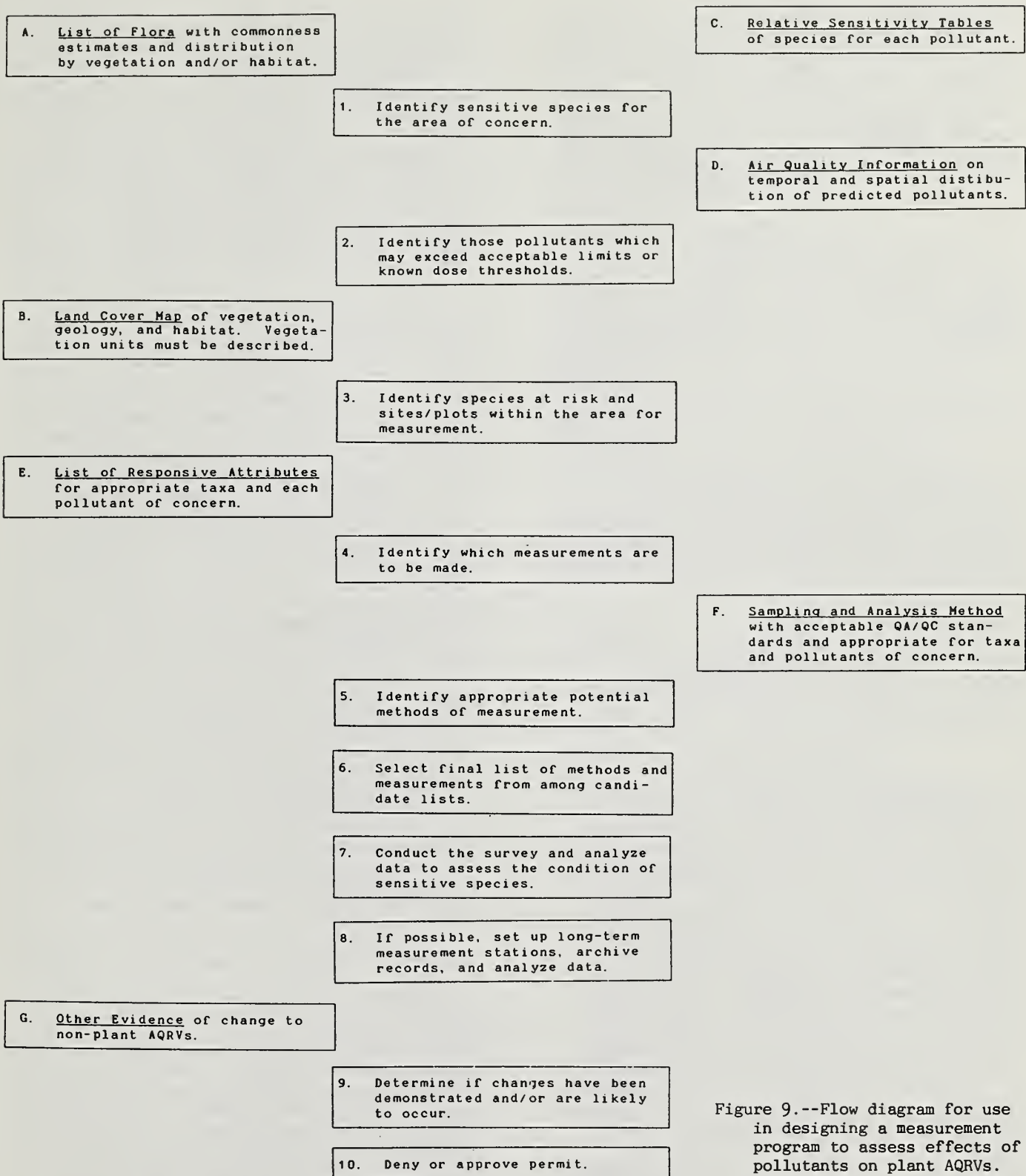


Figure 9.--Flow diagram for use in designing a measurement program to assess effects of pollutants on plant AQRVs.

attributes of sensitive species that clearly show diagnostic responses to pollutants. Injury atlases illustrating damage and stress symptoms are a good source of clues as to appropriate attributes to measure; for example, Jacobson and Hill (1970), U.S. Forest Service (1973), Malhotra

and Blauel (1980), and Thompson, et al. (1984). Table 15 illustrates the type of information required for each pollutant of concern.

Sampling and Analysis Procedures

For each species and attribute, there must be

Table 15.--Examples of the kind of measurement and methods required for the detection of changes in atmospheric pollutants.

Pollutant & reference	Sensitive taxa	Responsive attribute	Measurement method	Sampling
Sulfur dioxide (LeBlanc and Rao 1975, Hale 1982, Wernmore 1983)	Lichens (e.g., <u>Xanthoparmelia cumberlandia</u>)	Disappearance of taxa Frequency of occurrence Sulfur content	Former and present range Present range and frequency Tissue analysis	From published lists and maps, from herbarium searches, and broad areawide surveys, distribution mapping Lichens to be collected from relocatable plots
Ozone (Heath 1975, Stolte and Bennett 1986)	<u>Pinus contorta</u> (lodgepole pine)	Foliage	% leaf flecking Representative leaf length % leaf retention	Plots located within the species range using vegetation map. They should be accessible to trails or roads, have more than 30 trees which are healthy and large enough to allow repeated sampling. 5 branches are sampled from each tree.

an appropriate method of assessment of pollutant effect. The fifth column of table 15 lists such methods. Handbooks with acceptable methods must be found or developed and refined as necessary. These methods and sources are discussed later in this section.

Changes in Non-Plant AQRVs

This information is included in the decision tree to illustrate a complete permitting process. Procedures are outlined in other sections of these protocols to measure non-floristic AQRV's.

The Decision Process

With the assembled data and information sets on hand, the measurement methods can be selected. The flow diagram (fig. 9) illustrates this process with numbered steps. At step 1, the potential study species are identified by comparing the list of the flora (A) with the list of sensitive species given in the sensitivity tables (B). At step 2, the potential pollutants--those which may increase to unacceptable levels--can be derived from the air quality information (D), and at step 3, a match of this information with a list of species with known sensitivity to the appropriate pollutant (C) helps to set priorities for studies in the area of concern and leads to the identification of sites at which measurement could be made.

Sites where the sensitive species are present may be determined from the land cover and species distribution maps (B). Site selection should also consider predicted or known pollution patterns (D). If pollutant distribution data are not available, then the sensitive species must be monitored over its entire range. If the areas over which elevated pollutant levels are expected to occur overlap with the distribution of sensitive species, these areas should be intensively monitored. Those areas which are less likely to be impacted should also be

monitored. Final placement of study plots or location of samples will depend on which plant attributes are to be monitored.

Step 4 decides which measurement are to be made. Table 15 provides an example of data for set E, and lists--for two pollutants and some sensitive taxa--those attributes which are responsive or readily affected by the pollutant. For example, needle length and needle retention in Pinus contorta are affected by ozone levels. Similarly, step 5 decides the methods of appropriate measurement. For example, for Pinus foliage, the method of Stolte and Bennett (1986) using large-scale random sampling would be a good candidate.

Step 6 involves final selection of methods and measurements from among a candidate list derived in steps 4 and 5. Final selection will depend on many considerations: for example, the presence of sensitive species and attributes, the availability of effective methods, available labor and time, and coordination with other ongoing monitoring programs. Often the permit decision must be made in a very short time frame: less than a growing season. In such a case, the FLM would need to proceed to step 7.

An important decision included in step 8 is whether only short-term studies are mandated or whether long-term monitoring can be attempted. (Strategies for long-term monitoring sites are discussed later in this section.) From scientific and protection points of view, long-term studies (step 8) are desirable. They will provide the most reliable assessment of effects and also easier decisions in the case of future new permit applications and permit reviews. Therefore, it is recommended that, within constraints of funds and time, step 8 be given serious consideration. This step can be done concurrently with short-term assessments, or to build on short-term data sets gathered during expediently made permit assessments.

Following the surveys and analyses (steps 7 and/or 8) the FLM must review the information and determine, as per step 9, the health and risk of the plant components of the class I area. Other evidence (G) will be brought to bear on this by the FLM during the PSD permitting decision proper.

General Guidelines for Sampling and Analysis

Sampling and analysis will depend on the species and attributes selected in the search for sensitive systems, and also upon whether long-term monitoring or only short-term survey studies are being conducted. Within reason, we recommend that both monitoring and survey methods be as similar as possible--similar with regard to sample size and permanent marking or accurate location of sampling points or plots. Sample size should always be adequate. Methods manuals should provide information on sample size, but if new methods are developed, a competent statistician should be consulted.

Sampling along gradients of airflow, and thus along possible gradients of pollution, provides better, although never incontrovertible, evidence for cause and effect. If long-term sampling is

initiated, the pollutant can be regarded as an independent variable, and the effects of other factors such as naturally fluctuating climatic factors can be taken into account. Further information on cause and effect develops as the database grows over time, and when reliable co-measurements of physical and chemical factors are collected. The re-sampling of permanent plots and tagged individual plants over time reduces the problem of spatial variability. Most growth and physiological activities decline in late summer and early fall; sampling at this time will be the sum total of the current season's growth and can reduce some of the seasonal and temporal variability.

In most cases, potential gradients of air flow or pollution will not be known or pronounced enough to suggest where to locate sample points. Therefore, we generally favor the random placement of plots or transects within the system which contains the species of concern. Permanent marking is to be preferred and, if necessary, stubbornly lobbied for in those Class I areas where managers may object. There are markerless methods but they are costly and not always reliable. Methods of marking with minimum impact are discussed in Zedaker and Nicholas (1986). We recommend that each study plot be thoroughly described by the methods of Walker et al. (1979). These descriptions form a necessary database and give clues as to factors controlling plant stress other than pollutants. Photography of plots and individual plants is a valuable supplement to plot description. Photographs can record for posterity what the observer has not yet learned to spot, or what does not seem important at the time.

Table 15 illustrates the types and methods of measurement which could be used for the two pollutants--ozone and sulfur dioxide. The table further illustrates the kinds of considerations that FLMs and experts will need to make in deciding an appropriate measurement and its sampling method. The annotations concerning ozone and sulfur dioxide effects help illustrate the process of method selection.

Ozone does not leave a residue within the plant to be measured, whereas sulfur dioxide may be retained as sulfate or some other sulfur compound. Therefore, tissue chemistry is not useful for ozone detection; assays of products of oxidation from ozone injury are not appropriate in field techniques since the products are ephemeral. Lichens and bryophytes have not been shown to be sensitive to ozone and would not, therefore, not be used in an assessment of ozone effects. Some pines, however, are sensitive to both sulfur dioxide and ozone, and assessment methods could be combined (see Stolte and Bennett 1986). We recommend the Milkweed measurement method of Bennett and Stolte (1985) as a model of an assessment method.

Analysis of tree rings for accumulated trace metals (Berish and Ragsdale 1985) and analysis for reduced growth resulting from poor air quality (Nash et al. 1975) are attractive methods since they have the potential to show previous regimes of effects of pollutants on growth. Generally, however, we caution against tree ring

analysis since it is technically demanding and expensive. Also, cross-contamination of tree rings is possible and any reduced growth effects can seldom be related to specific pollutants.

Perhaps the most difficult part of the plant protocols will be the determination of the significance of observed plant responses, and what the continued or ultimate consequences or those responses imply for the plant population. It is upon these prognoses that the permitting decision will rest.

Long-Term Monitoring: Measures and Basic Sampling Design

When a specific pollutant is not identified, or for such concerns as acid deposition that may cause ecosystem-level effects, it is recommended that a basic and long-term monitoring effort be conducted.

The original list of the flora (data set A) should be field checked. Special care should be taken to have correct identification and herbarium archiving to avoid incorrect conclusions about future losses of species.

Table 16 lists the principal attributes recommended for measurement. Tables 17 and 18 and figures 10, 11, and 12 provide some sample forms and scales for plot description by the releve method (Walker et al. 1979). A releve is

Table 16.—Measurements for vegetation and plant monitoring.

Attribute	Method	Reference
<u>Vegetation Map Units</u>		
Species composition	Releve	Walker et al. 1979
Site factors	Releve	Walker et al. 1979
Soils and geology	See Work Group 2	
<u>Permanent Plots (50X50m)</u>		
Photographs		Walker et al. 1979
Site factors		Walker et al. 1979
Soil	See Work Group 2	
Species Composition		Walker et al. 1979
- Cover value for shrubs, herbs, and ground layer		
- Density and diameters for trees		
<u>Fruticose and Foliose Lichen Plots (20X25 cm)</u>		
Photographs	35 mm camera	Hale 1982
Species check list	Listing	Hale 1982
Plant Chemistry		
- Pb, Cd, Zn, Ni, Cu, Mn	Atomic absorption	Allen et al. 1986
- Sulfur	ashing and HNO ₃ Leco combustion to SO ₂	See Work Group 2
<u>Evergreen Plants</u>		
Leaf necroses and chloroses	Comparison with color standards	e.g., Jacobson and Hill 1970
Elemental analysis	Atomic absorption	Allen et al. 1986
Leaf retention by age class	ashing and HNO ₃ See text	
<u>Trees</u>		
Tree ring growth analysis for each site	Tree coring and dendroecology	Nash et al. 1975
Historical record of pollutant deposition Pb, Cd, Zn, Ni, Cu, Mn,	Aashing and HNO ₃ , atomic absorption	Berish et al. 1985

Table 17.--Subjective environmental gradient scales to be used for completion of figure 10.

Site scale	Site moisture	Soil moisture	Summer Air temperature	Snow	Wind
1	Very dry, little or no moisture within 10 cm of surface, exposed to strong winds	Very dry, no apparent moisture, no clumping	Very cold sites, high altitude with north-facing slopes	Little or no snow cover in winter, ridge top sites	Completely sheltered from the wind
2	Very dry, little moisture near surface, somewhat less exposed sites	Very dry, some moisture but doesn't clump	Cold sites, high altitude with moderate solar exposure, north-facing coastal plain sites or flat sites extreme arctic coast	Little or no snow cover in winter, exposed slopes	Exposed to occasional very light (1-5km/hr) winds
3	Dry, some moisture near the surface, very exposed	Dry, clumps but then crumbles	Cold sites, moderate altitude flat coastal plain sites	Slopes usually snow covered in winter	Very light winds common
4	Dry, some moisture near the surface, somewhat less exposed sites	Dry, clumps and stays in a ball	Cool sites, flat surface in Arctic Foothills	Slopes snow covered in winter, snow melt by late May	Occasional light (5-10 km/hr) winds
5	Moist, top 10 cm continually moist to wet, moderately well-drained sites	Moist, binds but can be taken apart	Moderate temperatures, south-facing slopes on Arctic Coastal Plain or high mountains	Shallow depressions, somewhat prolonged snow cover, melt by early June	Light winds common
6	Moist, top 10 cm near saturation, less well-drained sites	Moist, binds completely into gooey ball	Moderate temperatures, south-facing slope, Arctic Foothills	Snow patches, snow melt by late June or early July	Occasional moderate (20-30km/hr) winds
7	Wet, continually saturated soil but no standing water	Wet, can squeeze some water out	Moderate temperatures, flat site at intermediate altitudes south of Brooks Range	Snow patches somewhat later snow melt by late July	Moderate winds common
8	Wet, usually with standing water early in summer	Wet, can squeeze lots of water out	Warm temperatures, flat site, lower altitudes south of Brooks Range	Snow patches, later snow melt, early August	Occasional strong winds (40-50km/hr), winds otherwise light
9	Very wet, usually with standing water late in summer	Very wet, totally saturated	Warm, south-facing slopes at intermediate altitudes in interior Alaska	Snow patches, very late snow melt, late August	Strong winds common, winds otherwise moderate
10	Very wet, deep standing water year round	Very wet, soil taken from under-water	Warmest south-facing slopes at lower altitudes in interior Alaska	Snow patches, very late snow melt, sometimes may have snow cover all year	Strong winds common, occasional very strong (>60km/hr) winds

Table 17. --Continued.

Site scale	Surface age	Stability	Cryoturbation	Fire	Overall vegetation	Tree layer	Shrub layer	Herb layer	Ground layer
1	Constant disturbance	Completely unstable always moving (e.g., dunes)	0% of surface disturbed	No evidence	Barren, very sparse vegetation	Scattered small trees (<5cm dbh)	Shrubs rare	Very widely scattered herbs	Very sparse
2	Less than 1 yr since severe disturbance	Annually unstable (e.g., avalanche slopes, river bars)	< 1%	Buried charcoal	Prostrate scrub or lichen meadow	Scattered medium trees (5-15cm dbh)	Scattered dwarf shrubs (0.1-0.5m)	Scattered short herbs (<0.1m)	Scattered
3	1 - 10 yrs	Periodically unstable (e.g., 50-yr flood plain)	1-2%	Charcoal on surface rare	Graminoid meadow	Open small trees	Scattered medium shrubs (0.5-2m)	Open short herbs	Open thin cover (<2cm)
4	10 to 100 yrs	Unstable, vegetation in patches, on slope	2-5%	Charcoal on surface common	Tussock graminoid meadow with thick moss	Closed small trees	Open dwarf shrubs	Closed short herbs	Closed thin cover
5	100 to 1000 yrs, last disturbance during late Holocene	Unstable, vegetation in patches, on flat	5-10%	Older burn, living trees have burn scars	Dwarf scrub	Scattered large trees (>15cm dbh)	Closed dwarf shrubs	Open medium herbs (0.1-5m)	Open moderate thickness (2-5cm)
6	1000 to 10,000 yrs, last disturbance during early to mid-Holocene	Moderately stable, open vegetation, on slope	10-15%	Older burn, regrowth of large trees (>15cm dbh)	Scrub	Open medium trees	Scattered tall shrubs (>2m)	Closed medium herbs	Closed moderate thickness
7	Old surface, last disturbance during late Wisconsin (30,000 yrs B.P.)	Moderately stable, open vegetation, on flat	15-25%	Older burn, regrowth of moderate-sized trees (5-15cm dbh)	Dense tall scrub or open small evergreen trees	Closed medium trees	Open medium shrubs	Open tall herbs (0.5-1m)	Open thick (5-15cm)
8	Old surface, last disturbance during early Wisconsin (30,000 - 70,000 yrs B.P.)	Stable surface, completely vegetated, moderate slope	25-50%	Recent burn, small trees and/or complete vegetation cover	Open medium-sized trees or dense small tree (<5cm dbh)	Open large trees (>15cm dbh)	Closed medium shrubs	Closed tall herbs (0.5-1m)	Closed thick
9	Very old surface, last disturbance during pre-Wisconsin time	Stable surface, completely vegetated, slight slope	50-75%	Recent burn, no regrowth of trees	Open large trees (>15cm dbh) or dense medium-sized trees (5-15cm dbh)	Closed large trees	Open tall shrubs	Open very tall herbs (>1m)	Open very thick (>15cm)
10	Very old unglaciated surface	Most stable surfaces, completely vegetated, flat	75-100%	Complete burn, no regrowth	Dense large trees (>15cm dbh)	Closed very large trees (>225cm dbh)	Closed tall shrubs	Closed very tall herbs	Closed very thick

Animal scales: 0 No sign

1 Slight evidence

2 Moderate evidence

3 Abundant evidence

Figure 10.—Sample form for releve site factors.

Releve No. _____ Map Name _____

Observer _____ Date _____

Master Map Code _____ Map Unit No. _____

Site Description and Site Factor Code (see Table 4-7) _____

Sample Area _____ Depth of Thaw _____

Slope Aspect _____ inclination° _____ Depth of Water _____

Site Scale (1-10):

(see Table 4-4)

Relief:

site moisture _____ Microrelief:

soil moisture _____ Type _____

temperature _____ Height _____ Width _____

snow _____ Mesorelief:

wind _____ Type _____

surface age _____ Height _____ Width _____

stability _____

cryoturbation _____

fire _____ (fire evidence _____)

Vegetation:

Age of Vegetation: Estimate _____ Evidence _____

Percentage Cover:

All vegetation _____ Tree layer(m) _____

Trees(>2m) _____ Shrub layer(m) _____

Tall shrubs(>2m) _____ Herb layer(cm) _____

Medium shrubs(.5-2m) _____ Ground layer(cm) _____

Dwarf shrubs(10-15cm) _____

Prostrate shrubs(<10cm) _____ Biomass (scale 1-10):

Graminoids _____ Overall _____

Forbs _____ Tree layer _____

Bryophytes _____ Shrub layer _____

Lichens _____ Herb layer _____

Rocks _____ Ground layer _____

Bare soil _____

Water _____ Photo Nos. _____

Table 18.—General landforms.

20	Dunes	55	Valley
21	active	56	depositional
22	inactive	57	erosional
25	Basin/depression	60	Mesa
26	thermokarst basin	61	footslope
30	Plains	62	sideslope
31	depositional	63	crest
32	erosional	70	Hills
35	Flood plain	71	footslope
36	channel	72	sideslope
37	active	73	crest
38	abandoned	80	Mountain
39	river bar/island	81	footslope
40	River terrace	82	sideslope
41	depositional	83	crest
42	erosional	98	Water
45	small delta		
50	Alluvial fan		
51	active		
52	inactive		

literally a "picture" of a plot or stand. These tables and scales were designed for an Alaskan research program, and serve only as a starting point for the FLM and must be modified for each new area. The basic sampling design calls for

Figure 10.—Continued

Releve No. _____

Animals:

Name	Scale (0-3)	Evidence
Bear	_____	_____
Caribou	_____	_____
Moose	_____	_____
Lemmings	_____	_____
Microtines	_____	_____
Ground squirrels	_____	_____
Ptarmigan	_____	_____
Other birds	_____	_____
Insects	_____	_____
Others	_____	_____

Plant Phenology:

Species	Stage
_____	_____
_____	_____
_____	_____
_____	_____
_____	_____

Soil:

Soil type _____ Parent material _____

Description (include horizon names, depths, color, texture, structure, character of boundaries, %rocks, %fiber, %mottles):

Photo Nos. _____ Soil sample top 10 cm _____

Disturbance:

Type _____ Age _____

Notes _____

Checklist:

() Mark location on photo	() Soil photo
() Mark location on map	() Vascular plant sample
() Soil sample	() Moss sample
() Tree core	() Lichen sample
() Vegetation photo	() Permanent plot staked & marked

several equivalent landscape units, such as small alpine basins, to be surveyed and mapped. These units should be selected, wherever possible, along known or predicted airflow paths where gradients of pollution might be expected. Permanent plots that contain the growth forms being studied should be established within each basin. These growth forms are fruticose and foliose lichens, evergreen plants, and trees. Individual plants or plant parts must be permanently tagged or able to be reliably re-identified.

Requirements

Estimates of person-day and field equipment requirements are given in tables 19 and 20. These estimates may be rather low, and may need to be increased for sites with poor accessibility.

Field Methods

The initial regional survey of plot establishment should be done during the first growing season. Plots should be accessible but

Following field checking and appropriate updating, boundaries can be easily transferred to a 1:24,000 USGS topographic base map.

Each final map unit should be characterized for vegetation and landform cover. The method of Walker et al. (1979), which uses the releve technique (Westhoff and Maarel 1978), is quick and appropriate (tables 17 and 18, figs. 11 and 12).

Voucher collections should be made when rare plants or plants of uncertain identity are encountered. Standard herbarium techniques should be used. Figure 11 gives the needed plant collection information.

Soil information can be readily added to these geobotanical maps.

Mapping of each basin will require about 0.25 man days of aerial photo interpretation and 4 person days of field effort. Final plant determinations and drafting should be done in the laboratory.

Large plot location and description. In each landscape unit, large 50 X 50 m permanent plots should be located and established. These should contain good stands of fruticose and foliose lichens, evergreen plants (both shrubs and trees), and mature forest trees. In each unit a minimum of five plots should be set up to provide access to the required taxa. All taxa might be contained in a single plot. Plots should be staked, tagged, located precisely on the geobotanical maps, and reference sightings made to prominent terrain features. A series of oblique photographs should record general aspect and vegetation of each plot. Each plot should be described with the releve method, which will provide a complete inventory of flora and estimates of individual species abundance. Cover values should be recorded for shrubs, herbs, and ground layers. Trees should be recorded by species, number, and dbh (diameter at breast height).

Set-up and description of each plot should take about 0.25 person-day.

Attribute Sampling and Monitoring

Lichens. Ten small 20 X 25 cm microplots should be set up in each of the five larger (50 X 50 m) macro-plots to record ground and rock lichen communities. The plots can be marked with small stainless steel stakes or small holes in rock surfaces using a star-rock drill and hammer. The basic method is that of Hale (1982). Vertical whole plot photographs and oblique aspect photographs should be taken for each plot. A complete as possible listing of lichens is made. Voucher collections should be made outside of the microplots. A large handful (5-10 g) of each common fruticose or foliose lichen is collected from within each 50 X 50 m plot for elemental analysis (see table 16). Samples should not be collected into brown kraft paper bags because of the possibility of sulfur contamination. Similarly, zinc contamination may result from using ordinary plastic bags. Synthetic bags made of materials such as tyvek are preferable. The bags should "breathe" and the lichens should be dried in the bag. Foreign

material (other lichens, insect cases, moss, etc.) should not be removed from air-dried specimens. Specimens should not be oven-dried or washed. Samples should be ground in a Wiley mill to pass a 20-mesh screen.

Setting up and recording 10 microplots in each macroplot and sampling for elemental content of lichens takes about 0.5 of a man day.

Evergreen foliage. Evergreen species should be sampled within the macroplots available. Evergreen shrubs or trees are best; evergreen herbs are of dubious value. When possible, the same species should be used throughout a wilderness area. Ten individual plants should be tagged and their locations recorded in a macroplot. Ten individual branches should also be tagged on each plant to allow for replication and future repeated measurements. Photographs of each individual plant should be taken.

Each branch is examined against standard color charts and photographs of leaf damage from known pollution effects, and scored for signs of necrosis (flecking, tip-die-back, etc.) and chlorosis. Further literature and method development is needed here. A good start is Miller and McBride (1975).

Samples of leaves of each age class (about 20 grams fresh weight) should be taken from neighboring unmarked plants. Dead and living leaves should be collected separately. Five samples per macroplot are recommended.

A record should be made of leaf numbers per age class for each marked branch.

Tree wood. Methods of tree coring and wood trace element analysis are well worked out by Berisch and Ragsdale (1985). Within the 5 macroplots, 10 trees of each dominant species should each be cored 3 times at breast height. Two of the three cores are used for element analysis in 5-year increments, and the remaining core is used for growth analysis. In subsequent years, only short cores will be necessary. Each tree should be photographed, tagged, and its location recorded. Coring of 20 trees takes about 0.5 man day.

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Rocky
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Southwest



Great
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Rocky Mountain Forest and Range Experiment Station

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